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Erosion resistance properties of fiber-reinforced soil

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ABSTRACT :Mixing short fibers with soil enables construction of a tough embankment slope presenting a significant resistance against erosion by rainfall. The present paper demonstrates from indoor erosion tests that slopes made of short fiber reinforced soil is excellent in erosion resistance, and such mix is suitable for constructing multi-natural green slopes of embankment.

1. INTRODUCTION

Rainfall erodes cutover slopes of mountains or hills and sandy soil slopes. In eroded slopes, surface soil which is bed for vegetation tends to flow away, impeding thereby formation of stable slopes harmonized with the natural environment.

Fiber materials have been utilized in civil engineering for drainage, anti-erosion, reinforcement of banking. Techniques using fiber materials for slope protection and anti-erosion include among others the following.

(1) Slope protection practices

1° Covering with synthetic fiber cloth, mat

2° Covering with polymer sheets

3° Netting

4° Covering, protection using fabric forms

5° Giotextile:

(2) Vegetation practices

1° Vegetation mat:

2° Seed bag:

3° Vegetation streaks:

4° Spraying/surface layer covering:

These slope protection and anti-erosion practices are widely implemented in diversified fields. They cannot, however, modify the characteristics of soil in situ liable to flow away due to rainfall. They are classified into two large categories: preventive measures against rain penetration and reinforcing technique limiting deformation by reinforcing the surface layer.

In contrast with these methods, the short-fiber reinforced soil technique is characterized by utilizing the soil in situ apt to flow away due to rainfall, regenerating it to form a tough slope resistant to erosion, which can serve as an appropriate bed for vegetation. In this practice, synthetic fibers such as polyester of 1 to 100 De* are mixed with soil or stabilized soil. The mix proportion of fibers to soil is about 0.01 to 2 % on the basis of dry weight of soil. The fiber reinforced soil is an improving technique, utilizing the principle of the traditional practice of mixing straw in soil material for wall, plant cultivation bed, etc., can offer unparalleled toughness compared with conventional soil materials.

*(De is short for Denier: Denier is a unit of finesse for yarn equal to the finesse of a yarn weighing one gram for each 900 meters)

The author et al. conducted indoor erosion tests on the effects of the short-fiber reinforced soil technique. The experimental results are reported below.

2. TEST PRACTICE

2.1 Fibers

Fibers for the technique discussed here must satisfy these conditions;

1° can be uniformly mixed with soil,

2° have a sufficient tensile strength,

3° be ensured to present a sufficient tensile strength for a long span of time, when a significant biological and chemical erosion resistance is required,

4° low cost convenient as an earthwork material,

5° easily available on the market and stable quality, etc.

Polypropylene and polyester fibers are typical examples meeting the requirements above, generally used in the short-fiber reinforced soil technique.
Three different types of fibers (short fibers, net pieces, water absorbing fibers) were used in the tests, as shown in Table 1.

Table 1 Properties of fibers

Kind of fiber	Material	Geometry	
		Finesse	Length/Dimension
Short fiber	Polyester	6De	30mm
Net piece	Polyethylene	Yarndiam. 0.1mm	Opening 4×4mm Piece size 50×100mm
Water absorbing fiber	Acrylic polymer	5De	50mm

2.2 Soil materials

Three soil materials were used in the tests, sandy soil, clayey sand and decomposed granite. Table 2 shows the physical properties of the soil materials.

Table 2 Physical properties of soil

	Grain size distribution(%)				ρ_{dmax}	ω_{opt}	ρ_d	ω
	Gravel	Sand	Silt	Clay	(g/cm³)	(%)	(g/cm³)	(%)
Sandy soil	2	94	4		1.667	16.7	1.480	11.3
Clayey soil	2	58	20	20	1.516	24.5	1.154	30.0
Decomposed granite	95.4		4.6		1.908	13.0	1.571	7.4

The dry density ρ_d and water content ω given in the table are the values obtained for the soil materials reinforced with short fibers, compacted in about three layers in a specimen box (wooden box drainable, 100 cm long, 40 cm wide, 20 cm deep). The specimens were prepared by agitating soil materials with a natural water content in a horizontal dual-axis mixer (capacity of 50 liters) and mixing fibers.

2.3 Test apparatus and practice

The wooden boxes drainable shown in Fig. 1 and Photo. 1 charged with short-fiber reinforced sandy or clayey soil, were installed at an angle of 45 degrees. Water was sprinkled by nozzles located 4 m above the boxes for 4 hours to simulate a rainfall intensity of 100 mm/hour. The configuration of the test apparatus was determined in such a manner that the rainfall intensity may be uniform at the level of the specimen soil surface in the specimen box. Besides, the rainfall intensity was checked at some points during the tests to avoid its variation at the level of the specimen surfaces.

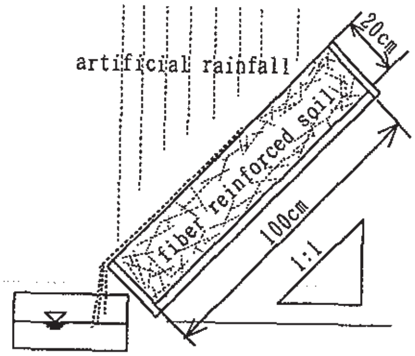

Fig .1 Apparatus of erosion test

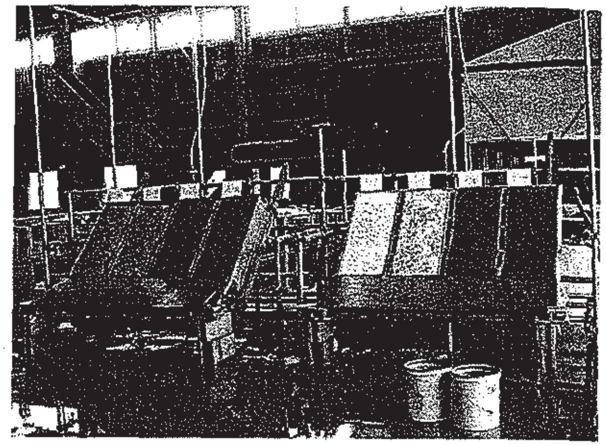

Photo.1 Test apparatus

During the tests, runoff (water flowing on the surface) and soil which has flown out were collected to observe their change with time. Immediately after the erosion tests, the penetration resistance was measured by Yamanaka-type soil hardness tester.

3. EXPERIMENTAL RESULTS

3.1 Change with time of soil flow rate

The flow rate of the sandy soil and decomposed granite specimens was measured every 30 minutes after the start of rainfall. Figs. 2 and 3 are the plots of flow rate against time. The flow rate of clayey sand was so small that its measurement was impossible, offering no data for comparison.
As known from the figures, sandy soil without fibers began to flow immediately after rainfall; the flow rate increased gradually to collapse in the specimen box. On the contrary, in the case of short-fiber reinforced specimens of sandy soil, there was little erosion, and about 4 hours after the start, when the rainfall intensity was 100 mm/hour, a very small amount of flow was observed.

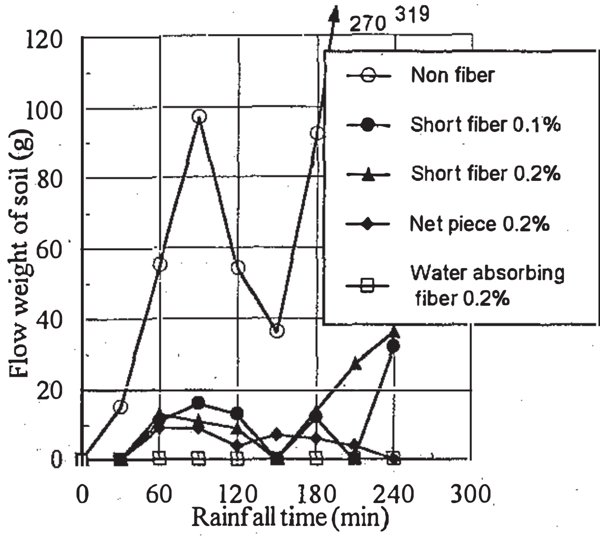

Fig.2 Flow rate of the sandy soil

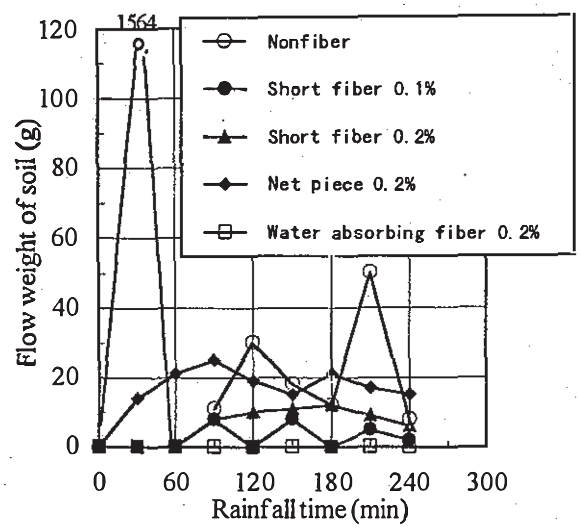

Fig.3 Flow rate of the decomposed soil

The decomposed granite without fibers showed a remarkable collapse in the specimen box about one hour after the start of rainfall, and a large amount of specimen flowed; then, the flow rate decreased. In contrast, the flow rate of the fiber-reinforced specimens was very small. The flow rate was almost zero, in the case of the specimen containing 0.2 % water absorbing fibers.

Photo 1 shows the state of collapse due to rainfall, of the sandy soil without fibers, Photo 2 the state of the reinforced specimen (with 0.2 % short fibers) 4 hours after the start of rainfall. As shown by the photo, though fine particles in the surface layer of the reinforced specimen were washed away and fibers were exposed, there was no flow of soil material. This demonstrates that the mixture of short fibers to the sandy soil offers a high erosion resistance.

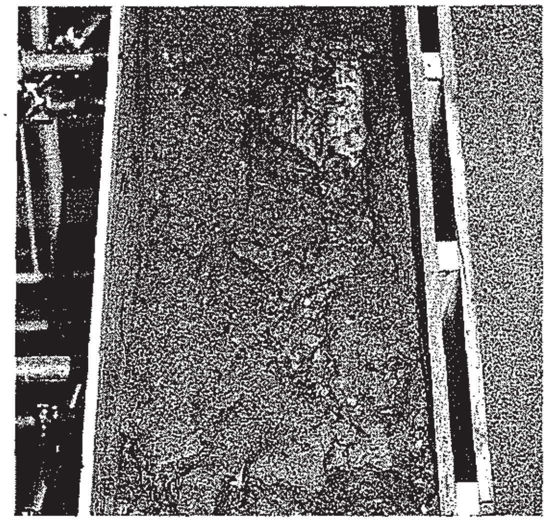

Photo. 1 State of the un-reinforced specimen (sandy soil without short fibers)

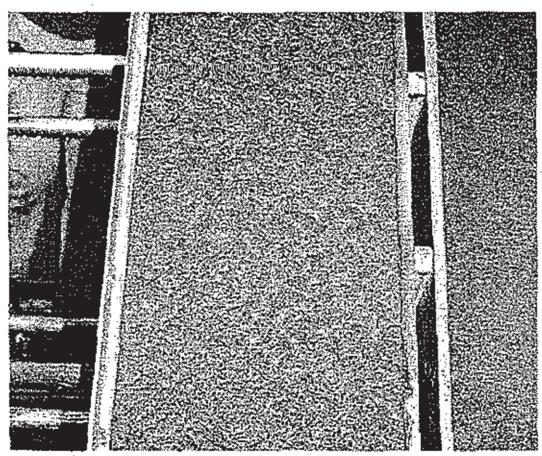

Photo.2 State of the reinforced specimen (sandy soil with 0.2% short fibers)

3.2 Hardness of soil

Fig. 4 shows the penetration resistance determined by Yamanaka-type soil hardness tester immediately after the erosion tests. The penetration resistance of the surface layer of each specimen without short fibers was low, 0.1Mpa. With increasing content of short fibers or net pieces, the penetration resistance became larger. In the case of specimens containing water absorbing fibers, its surface after rainfall is soft, covered with a gel film, presenting the smallest hardness among the three different types of material. The smallest flow rate of soil of these specimens can be explained as follows ; the soil absorbing fibers swelled with humidity to form a gel surface layer, which prevents penetration of rain, and the gel system retained fine soil particles.

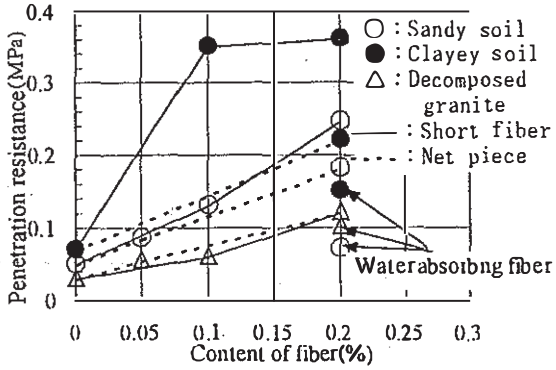

Fig.4 Penetration resistance after erosion test

4. CONCLUSIONS

We have written many papers demonstrating excellent physical properties of short-fiber reinforced soils which are hard to break and very tough. The principle of this practice is to modify a soil material which is isotropic into a non-uniform material, avoiding thereby destruction due to stress concentration, that is to say, avoiding generation of shear section to improve the toughness against destruction. In the course of studies, the excellent characteristics of short-fiber reinforced soil as a compound material have been verified, i.e.,

1° it can disperse the directions of microcracks,

2° it can avoid stress concentration due to microcracking,

3° short fibers in the system work as bridges which prevent particle blocks from moving due to a shear force.

The increase of strength and toughness by reinforcing with short fibers varies with the grain size distribution of soil, kinds and characteristics of short fibers (finesse, length), and whether or not stabilization is performed. Consequently, no quantitative criteria for design and practice has been established. So at the present stage, the strength is currently determined by mechanical tests on the soil in the site concerned, reinforced with short fibers.

Different from the foregoing studies based on tests on the mechanical properties, the research presented in this paper has demonstrated the facts below through the indoor tests on the resistance against erosion effect of rainfall.

(1) The rainfall erosion resistance of sandy soil is enhanced by mixture of a small amount (0.1 %) of short fibers.

(2) Water absorbing fibers swell to form a gel layer which prevents water penetration through the earth surface, retaining soil particles.

(3) Since the soil hardness, i.e. penetration resistance increases with the content of fibers mixed in soil, the penetration resistance of saturated short-fiber reinforced soil can be regarded as an index for evaluating the erosion resistance.

Therefore, mixture of 0.1% or more fibers in sandy soil will offer an enhanced erosion resistance. This percentage is an index useful for planning the mixture proportion.

There is a case the short-fiber reinforcing was implemented for a bank slope and its follow-up research has been continued. The research has shown that, in the reinforced lot, no rill erosion occurs and roots of plants are tangled with short fibers, presenting a great tensile strength.

Applications of this technique, using recycled sandy soil produced in work sites, include maintenance of soil structure for creating a surface layer which does not flow away under the influence of rainfall, construction of multi-natural revetments.

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