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Reinforcement of very soft ground using bamboo cross beam with polymer net

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ABSTRACT: In construction of embankment on soft reclaimed ground, sheets and polymer nets are widely known as the suitable materials for reinforcement. This project site was reclaimed with a cutter suction dredger and is totally covered with very soft materials at present. Therefore, more rigid reinforcing materials should be used for the reinforcement of the embankment. The bamboo cross beams and polymer nets, as the rigid reinforcing materials, have been proposed to be incorporated into this project. However, the guidelines of the design and construction of the embankment using the above reinforcing materials have not been well-established due to the insufficient technical information resulting from scarcity of the preceeding works. To determine the design parameters and execution procedures, various field tests were conducted prior to commencement of the permanent work. As a result of these field tests, it is shown that the vertical load of the embankment is mainly supported by the bamboo cross beams.

1 FIELD TEST

1.1 Soil conditions

The field tests were conducted on the very soft ground reclaimed by a cutter suction dredger.

The properties of the soil on the site are shown in Fig. 1.

The soil profile at the site is mainly composed of clayey silt corresponding to C_H according to the Japanese Unified Soil Classification System. The natural water content (Wn), unit weight (γt) and cohesion (c) of the surface soil are Wn=150%, γt=1.3gf/cm³ and c=0.007kgf/cm², respectively. The surface soil is considered to be in an ultra soft state.

1.2 Outline of field test

Only few construction records are available for the embankment reinforced by bamboo cross beam and polymer net method therefore, there are still some uncertain parameters in the design and construction details. The field tests were conducted in advance of the permanent work to determine the design and construction parameters.

(1) Trial embankment

The location of a trial embankment was selected as shown in Fig. 2 taking into account the soil conditions of the existing ground at the project site.

The trial embankment as shown in Fig. 3 consisted of 60m in length, 60m in width and 0.5 to 1.5m in height and was constructed with the granulated slag. The properties of the granulated slag are shown in Table 1.

The trial embankment was constructed by the following procedure:

1) Assembly of the bamboo cross beams on the existing ground.
2) Installation of the polymer nets on the bamboo cross beams.
3) Spreading the granulated slag over the polymer nets in a slurry state in 2 layers (30cm thick each).
4) Levelling the embankment with a mini-backhoe and a hand-dozer.

(2) Laboratory tests and field measurements

The following laboratory tests and field measurements were conducted,

1) Laboratory tests

a. Tension test of bamboo

The tension test was carried out for the bamboo in accordance with Japanese Indus-

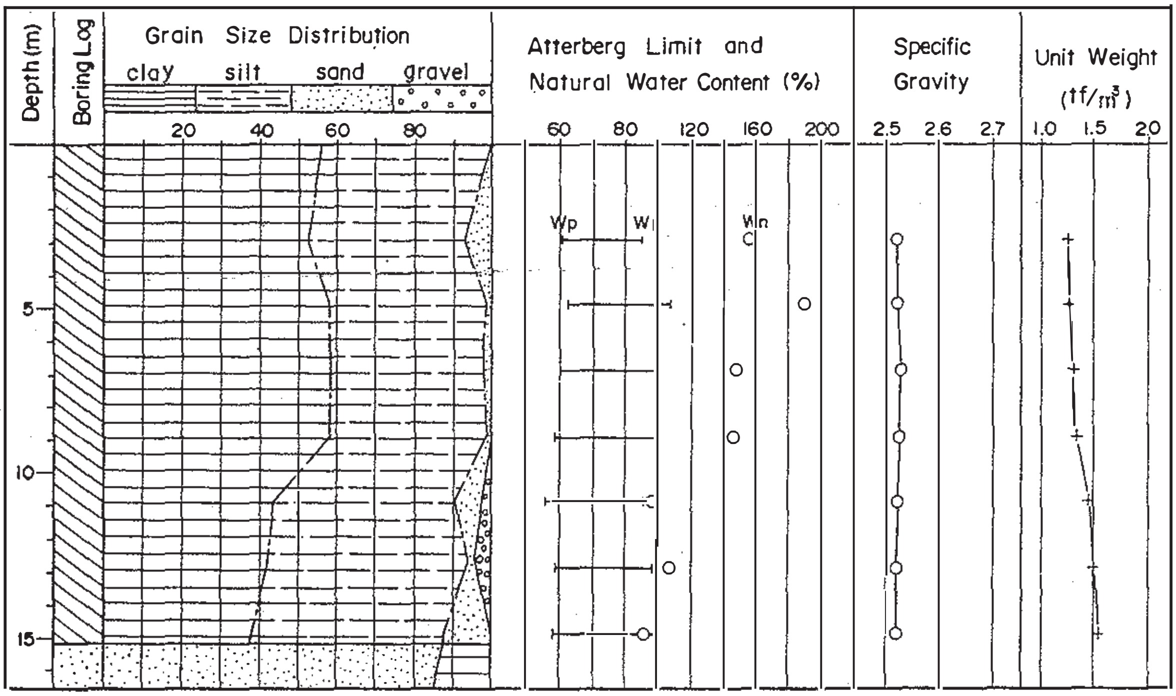


Figure 1. Soil profile and soil properties.

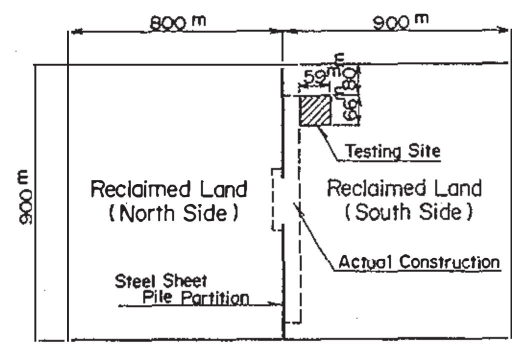


Figure 2. Location of field test.

trial Standards (JIS) Z 2112 to determine its mechanical properties.

b. Tension test of bamboo joints

The tension test was carried out for the bamboo joints to determine the tensile strength.

2) Field measurements

a. Measurement of settlement

The settlement of the trial embankment was monitored to determine the height of the permanent embankment.

b. Measurement of vertical force

The vertical force acting on the bamboo cross beams was monitored to estimate the vertical force on the bamboo in the permanent embankment.

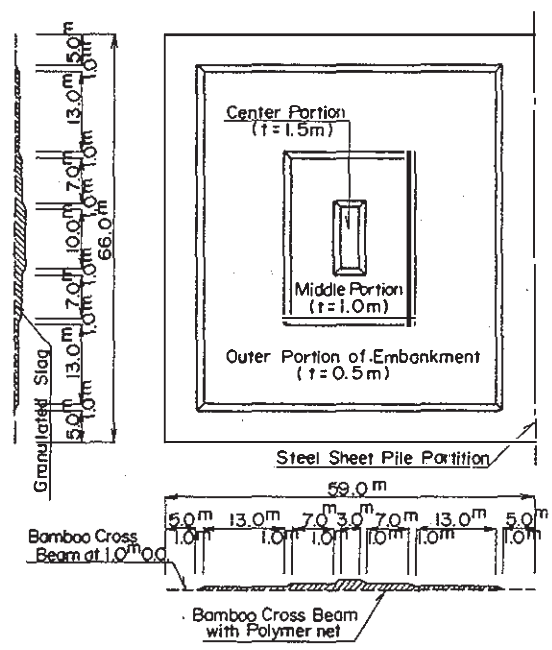


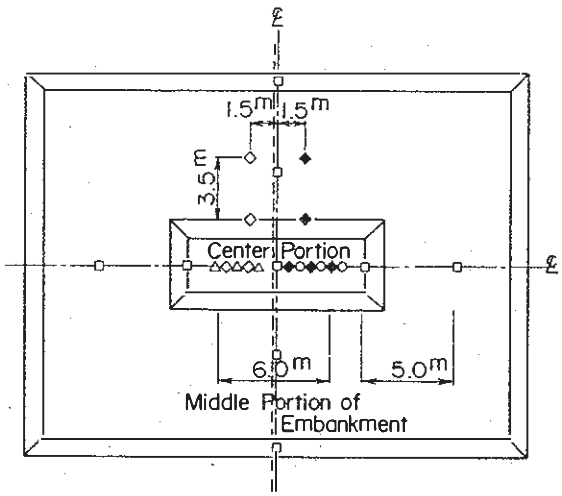
Figure 3. Dimensions of the trial embankment.

c. Measurement of tensile force

The tensile force acting on the bamboo cross beams was monitored to estimate the tensile force on the bamboo in the permanent embankment and to determine the spacing of the bamboo cross beams.

Table 1. Properties of granulated slag.

Items	Granulated Slag	
	Low Density	High Density
Specific Gravity	2.53~2.76	2.78~2.84
Unit Weight (tf/m^3)	1.3	1.3
Submerged Density	0.7 tf/m^3	0.9 tf/m^3
Internal Angle of friction	35°	35°
Coefficient of permeability (cm/sec)	$10^{-1} \sim 10^{-2}$	$10^{1} \sim 10^{2}$
California Bearing Ratio	20	20



Legend:
○ Reinforcing Bar Stress Transducer
◆ Strain Gauge
◇ Load Cell
△ Load Cell
------ Plastic Pipeline (For settlement Measurement Using a Pressure Gauge)
□ Wooden Settlement Plate

Figure 4. Locations of measuring devices.

For methods of the laboratory tests and field measurements, refer to Tables 2 and 3. The location of the field measurements is shown in Fig. 4.

2 RESULTS OF LABORATORY TESTS AND FIELD MEASUREMENTS

2.1 Tension tests of bamboo

Test specimens were taken from upper, middle and lower portions of each piece of bamboo and subjected to the tension tests in accordance with JIS Z 2112.

The results obtained were 1,600kgf/cm² for the mean tensile strength and 87,819 kgf/cm² for the modulus of elasticity. And it was found that the tensile strength of

Table 2. Laboratory test methods.

Test Items	Quantity	Methods of testing
Tensile strength test of bamboo	30pieces	In accordance with JIS Z2112. Samples were taken from upper, middle, and bottom portions of bamboo
Tensile strength test of bamboo joint section	2 units	Prior to the construction of the bamboo cross beam, the joint section is subjected tensile test.

Japanese Industrial Standards (JIS)

Table 3. Methods of field measurements.

Measured Items	Measuring Device	Quan-tity	Method of Measurements
Settlement	Wooden Settlement Plate	19	Settlement of existing ground and embankment was measured using woo-den settlement plate.
	Pressure gauge	1	Settlement of existing ground was measured using a water pressure gauge.
Vertical Forces	Earth Pressure Gauge	6	The vertical forces were measured using an earth pressure gauge.
Tensile Forces	Load Cell	3	Tensile forces were measured from the stresses acting on the polymer net.
	Reinfocing Bar Stress Transducer	3	Tensile stresses were measured from the stresses acting on the bamboo cross beam.
	Strain Gauge	12	Tensile stresses acting on the bamboo cross beam and net were measured using a strain gauge.

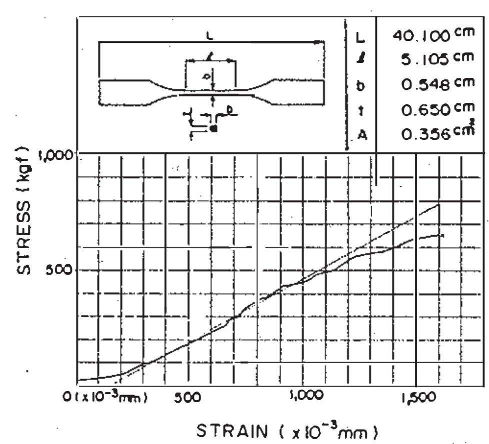


Figure 5. Result of tensile strength test.

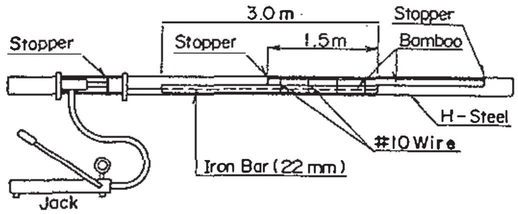


Figure 6. Hydraulic pressure jack, method.

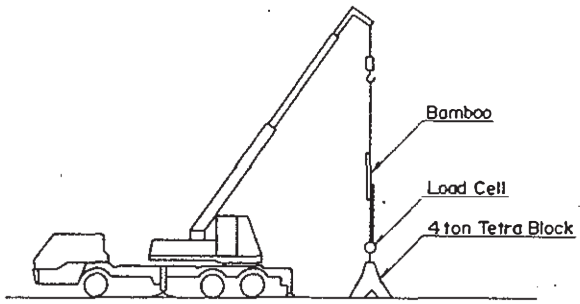


Figure 7. Pulling-up method employing crane.

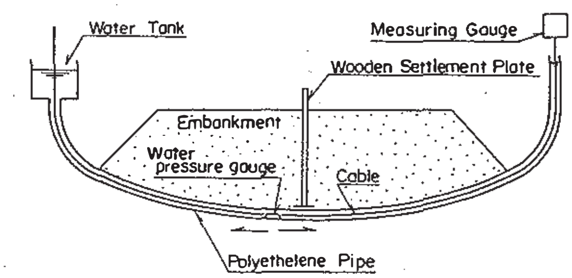


Figure 8. Pressure gauge method.

the bamboo depends on its age and not on the portion of the bamboo. Figure 5 shows the result of tests.

A modulus of elasticity of bamboo can be calculated in the following manner:

P = 650kgf (Breaking load)

$\sigma = P/A = 650/0.356 = 1{,}826\text{kgf/cm}^2$

P_p= 440kgf (Yield load)

$$E = \frac{Pl}{PA} = \frac{(440 - 100) \times 5.105 \times 104}{(982 - 339) \times 0.356}$$

$$= 75{,}825\text{kgf/cm}^2 \doteqdot 76{,}000\text{kgf/cm}^2$$

2.2 Tension tests of bamboo joints

The tension tests were conducted with the following 2 testing methods,

(1) Method employing hydraulic pressure jack

As shown in Fig. 6, a test piece with a 1.5m joint section was pulled using a hydraulic pressure jack. Table 4 shows the results of the tests.

Table 4. Test results of Hydraulic jack method.

Number of trials	Tensile strength
1 st trial	2.0 tf/pieces
2 nd trial	2.1 tf/ 〃
3 rd trial	2.0 tf/ 〃
Mean value	2.0 tf/ 〃

Table 5. Test results of pulling-up tests employing crane.

Number of trials	Tensile strength
1 st trial	1.4 tf/pieces
2 nd trial	1.8 tf/ 〃
3 rd trial	1.8 tf/ 〃
Mean value	1.7 tf/ 〃

(2) Method employing crane

As shown in Fig. 7, a bamboo joint section was pulled up by a truck crane. The pulling force was measured with a load cell installed between the joint section and a tetra-block. The test results are shown in Table 5.

Comparing the above test results, the values obtained from the crane method appear to be smaller than those from the hydraulic jack method. This may be due to the difference in loading procedures. Based on the test results, the tensile strength of 2tf/m at the joint section was employed for the design.

2.3 Tensile strength of polymer net

The polymer net material is polyethylene with a tensile strength of 5tf/m.

The polymer net samples were tested and observed to yield the above tensile strength.

2.4 Measurement results of field test

(1) Settlement

The settlement was monitored by 2 measuring methods: the wooden settlement plate method and the pressure gauge method as shown in Fig. 8. Figure 9 shows the maximum settlement at the center of the embankment: this settlement was 2.1m.

(2) Tensile force of bamboo cross beam

The tensile force was monitored using the reinforcing bar stress transducer and strain gauge installed on the bamboo cross beams, and maximum tensile force of 5tf/m was observed. This value may be affected by the bending tensile stress.

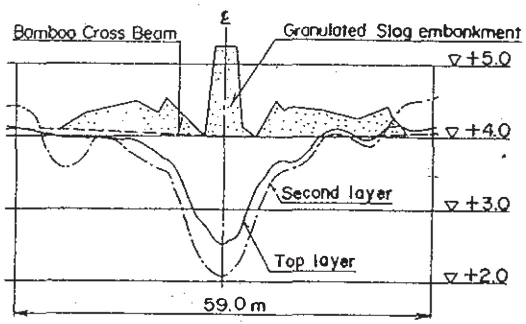


Figure 9. Measured settlement of embankment.

(3) Tensile force of net

To determine the tensile force acting on the polymer net, load cells and strain gauges were used as measuring devices. The results obtained from both instruments were almost the same, that is from 10 to 100kgf/m.

The difference in the tensile force between the bamboo cross beam and the net may be related to the difference in the modulus of elasticity between the materials.

(4) Measurement of vertical force

The vertical force was monitored using an earth pressure gauge placed on the bamboo cross beam. The values obtained using this gauge are almost equal to the value evaluated by the unit weight of the granulated slag and the thickness of the layers.

(5) Angle of inclination of materials and bulge radius of circumferential ground

For the cases where geotextiles are used, the following bearing capacity equation derived from Terzaghi's bearing capacity theory was proposed. (Yamanouchi & Gotoh, 1979)

$$qu = \alpha \cdot C \cdot Nc + T(2\sin\phi/B + Na/R) + \gamma \cdot Df.Na \quad \ldots\ldots (1)$$

where: qu = ultimate bearing capacity
α = shape factor of foundation
C = cohesion of soil
Nc,Na = bearing capacity factors
T = tensile force acting on geotextiles
B = width of foundation
γ = wet density of soil
R = bulge radius of circumferential ground covered by geotextiles
ϕ = angle of inclination of geotextiles

Figure 10 shows the measurement results of ϕ and R on site: ϕ is 8° to 13° and R 11.0m. When only polymer net is used, R should be a little smaller and ϕ a little larger. The above difference may be due to the difference in rigidity of the two materials.

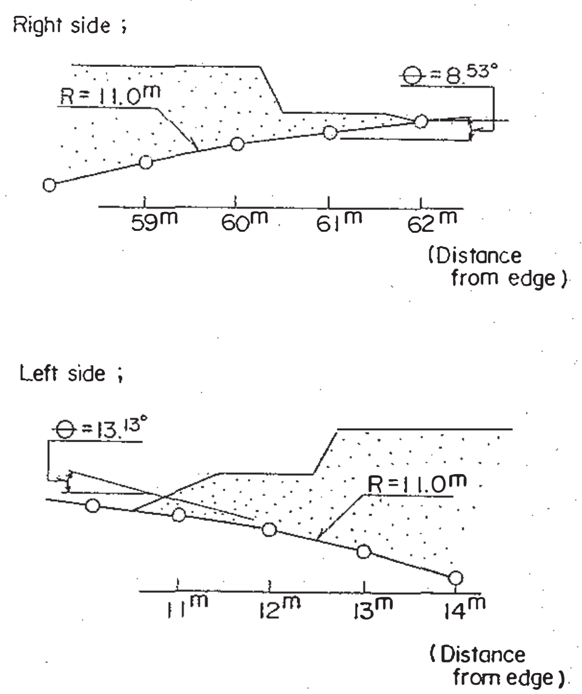


Fig. 10. Results of ϕ and R on site.

(6) Bearing capacity factor, Nc

The bearing capacity factor, Nc is obtained by the back calculation using Formula (1).

Following values based on the laboratory tests and field measurements are used for the calculation, and as a result Nc=3.35 was obtained using the following parameters:

C = 0.07tf/m²
T = 3.5tf/m
ϕ = 10°
R = 11.0m
B = 49.0m
γ = 0.3tf/m³
Df = 20cm

Terzaghi proposed to use Nc=5.71 in the

design of the embankment where the angle of internal friction of the soil is zero where the general shear failure is expected to take place, and Nc=3.81 where the ground is soft and the local shear failure is expected. In addition, (Watari et al, 1986) reported that Nc=3.19 was obtained from the tests for the similar soft ground.

Taking into account the rigidity of the bamboo cross beams, the calculated bearing capacity factor is considered reasonable as it lies between the values for the general shear failure and that for the local shear failure specified in Terzaghi's theory.

3 CONCLUSION

The results of the field tests on the trial embankment are summarized as follows:

(1) In the embankment constructed by the bamboo cross beam and polymer net method, the vertical load of the embankment is mainly supported by the bamboo cross beams. The polymer net protects the existing ground and embankment from being segregated and transmits the vertical load to the bamboo cross beams.

(2) The maximum tensile force acting on the bamboo cross beam was 5tf/m under the tested conditions.

(3) The angle of inclination of the embankment obtained in the tests was 8° to 13° and the bulge radius of circumferential ground was 11.0m.

(4) The bearing capacity factor, Nc of the existing ground was 3.53 when back calculated using Terzaghi's theory. The bearing capacity factor, if tested under similar ground conditions, might be considered to lie between the values for the general shear failure and that for the local shear failure specified in Terzaghi's theory.

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