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Testing methods of reinforcements for use in reinforced soil structures

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ABSTRACT : Japanese standards for Index tests on reinforcements and tests for evaluating interaction behavior of reinforcements and soil have been presented. Tests on both metallic reinforcements as well as geosynthetics have been covered. Relevant design guidelines and manuals published by other Japanese institutions have been also referred.

This report is the result of activities carried out by Japan Working Group on Testing Method, one of the working groups of Japanese Supporting Committee of the Asian Technical Committee for Earth Reinforcement (Chairman: Professor H. Ochiai).

1 INTRODUCTION

1.1 *Background*

To optimally select the reinforcements for construction of reinforced soil structures, it is important to fully understand the physical properties of reinforcements and to evaluate them as per design requirements. For this purpose, testing of reinforcement from various viewpoints is required. Such viewpoints include the functions and purposes required of the reinforcements, work environmnent at the time of construction of soil structures, and long-term durability against environmental factors. Also, it is essential to select the reinforcements that best suit the particular job specifications. This requires the testing of individual reinforcements. In addition, since reinforcements are embedded inside the soil, it is also important to determine the engineering properties arising out of interaction between reinforcement and soil. With these perspectives, methods of testing reinforcements as given in design guidelines and manuals published by various Japanese institutions have been presented in this report.

1.2 *Classification*

As indicated above, test items in this report have been broadly classified into tests for determining the characteristics of individual reinforcements known as Index tests (section 2) and tests for evaluating friction and other interaction behavior of soil and reinforcements (section 3). In view of the differences in engineering properties due to varied forms and shapes of reinforcements, test items in each of these broad categories have been further subdivided into tests on metallic reinforcements and tests on geosynthetics (see Table 1). Index tests on both metallic reinforcements and geosynthetics have been further subdivided into physical, mechanical and durability tests as given in Table 2. The contents of these tests will be described in this report, with reference to the representative manuals, guidelines and reports mentioned in Table 3.

Table 1 Classification of reinforced soil structure by material and shape of reinforcement

Material	Shape of reinforcement	Type of reinforced soil structures
Metal	Strip	Terre Armée, YORK-Type retaining wall
	Steel bar & anchor	Multiple anchored wall, TRRL anchors
	Grouted steel bar	Root piles, soil nailing, Micro piles, Multi-Anchorage system Reference: NATM, Ground anchor
	Iron grid	Wire wall, etc.
Fiber	Fiber	Fiber reinforced soil
Geosynthetic	Geotextile	Geotextile reinforced soil, Belt type reinforced soil
	Geogrid	Geogrid reinforced soil

Table 2 Physical, mechanical and durability tests

(a)Test items

Physical Properties A	1.Unit weight: Determination of mass per unit area and mass per unit length 2.Determination of thickness (at specified pressures) and diameter 3.Determination of size of strand
Mechanical Properties B	1.Tensile strength: Tensile test, Wide width tensile test 2.Creep test 3.Dynamic strength: Cyclic load test, Relaxation test 4.Others: Survivability (Installation damage) test, Puncture test, Tear test, Impact test, etc.
Durability C	1.Weathering test 2.Chemical degradation 3.Biological degradation and others

(b)Test implementation

Material	Shape of reinforcement	Physical properties A			Mechanical properties B				Durability C		
		1	2	3	1	2	3	4	1	2	3
Metal	Strip	Δ	Δ		□	O	O	O		O	O
	Steel bar	Δ	Δ		□	O	O	O		O	O
	Iron grid	Δ	Δ	O	□	O	O	O		O	O
Fiber	Fiber	Δ	Δ		O	O				O	O
Geosynthetic	Geotextile	Δ	Δ	Δ	□	□	O	O	O	O	O
	Geogrid	Δ		Δ	□	□	O	O	O	O	O

□ The test which must be always implemented beforehand to fined a design value

O The test which becomes necessary according to the situation (the environment condition, the building condition)

Δ The test which is implemented for the purpose of quality control of the reinforcements

2 INDEX TESTS ON REINFORCEMENTS

2.1 *Introduction*

For design and construction of reinforced earth structures, it is important to select the reinforcement according to the functions it is required to serve. For this purpose, it is necessary to conduct the index tests for determining the engineering properties of individual reinforcements. In this section, test items have been subdivided into tests on metallic reinforcements (section 2.2) and tests on geosynthetics (section 2.3). Section 2.4 deals with the determination of design strength from the index tests.

2.2 *Tests on metallic reinforcements*

Most of the test methods on metallic reinforcement materials are stipulated in Japanese Industrial Table 1 Classification of reinforced soil structures by material and shape of reinforcement.

Standards (JIS), and therefore this report only mentions the relevant number of these standards. In general, following types of metallic reinforcements are used in reinforced soil structures:

1. Metallic strip (M-1): JIS G 3101.
2. Steel bar with anchor plate (M-2): JIS G 3101.
3. Grouted steel bar (M-3): JIS G 3536.
4. Grouted steel bar and Metal others (R-M1): JIS G 3122.

(1) *Unit weight (A-1) and Diameter (A-2)*

Unit weight and Diameter are required for controlling the volume and other physical properties of reinforcements.

1. Metallic strip (M-1): JIS G 3193.
2. Steel bar with anchor plate (M-2): JIS G 3191.
3. Grouted steel bar (M-3): JIS G 3536. and JIS G 3109.
4. Grouted steel bar and Metal others (R-M1): JIS G 3122.

(2) *Tensile strength (B-1)*

Tensile properties of reinforcements such as maximum tensile strength, tensile rigidity, stress-strain relationship, etc., are necessary for design of reinforced soil structures (see JIS Z 2241.).

(3) *Creep (B-2)*

Since tension is applied to the reinforcements in reinforced earth structures for a long period of time, it is necessary to determine the deformation properties of reinforcements under sustained loading. Hence, a creep test is conducted to determine the permissible tensile

Table 3 Referred standards, manuals and report

(a) Application	Notation
Slopes & Excavations	AA
Embankments	BB
Wall Structures	CC
Foundations	DD

(b) Kind of reinforcement	Notation
Steel bar with anchor plate	MA
Metallic strip	MS
Geosynthetics (Geogrid)	GG
Geosynthetics (Geotextile)	GT
Grouted steel bar	MC
Metal (others)	MO
Geosynthetics (others)	GO

(c) Reference

Material	Code	Kind of Reinforcement	Application	Reference
Metal	(M-1)	MS	CC	PWRC (1990.05)
	(M-2)	MA	CC	PWRC (1994.10)
	(M-3)	MC	AA	JGS (1995.10)
	(R-M1)	MC, MO	AA	JGS (1995.03)
Geosynthetic	(G-1)	GG, GT, GO	BB, CC, DD	PWRC (1994.02)
	(G-2)	GG,GT	CC	PTRI (1992.11)
	(G-3)	GG, GT, GO	---	JIS L 1908
	(R-G1)	GG, GT	---	JGS (1994.01)

strength of reinforcements from load-strain-time behavior. Following are the relevant standards.

1. JIS Z 2271.
2. JIS Z 2272.

(4) *Dynamic strength (B-3)*

When reinforcements are laid in locations where load is applied repeatedly, strength of reinforcements is determined from repeated load tests. The relevant standards are given below.

1. JIS G 3536.
2. JIS G 3109.

(5) *Chemical properties (C-2)*

In view of the need to maintain the functions of reinforcements in the soil for an extended period of time, anti-acid and anti-alkali tests are conducted to determine the chemical resistance. The relevant standards are as follows:

1. JIS G 0591.
2. JIS Z 2371.

2.3 *Geosynthetic reinforcements*

Tests on both surface state and lattice-state reinforcements are described based on the design and construction manuals, guidelines and standards mentioned in Table 3.
However, geosynthetic materials will not be described here owing to the large variety of materials used as well as numerous synthetic fibers and resins from which these materials are manufactured.

(1) *Mass per unit area (A-1)*

Mass per unit area is tested for controlling the volume and physical properties of reinforcements.

1. Geotextile and Geogrid (G-1): The mass per unit area of 3 square test samples of 20 cm x 20 cm is measured, with the average to be expressed in g/m^2.
2. Geotextile and Geogrid (G-3): JIS L 1908.

(2) *Thickness (A-2)*

Thickness is tested for classifying reinforcements as well as for controlling the volume and physical properties of reinforcements.

1. Geotextile (G-1): The thickness of a 10 cm x 10 cm test sample under the pressure of 20 g/m^2 is measured. The average value of 5 test samples determines the standard thickness.
2. Geotextile and Geogrid (G-3): JIS L 1908.

(3) *Apparent opening size and size of strand (A-3)*

To evaluate the filtration characteristics of geosynthetics, apparent opening size test and test of size of strand are conducted.

1. Geotextile (G-1): Glass beads of the standard grain diameter are placed on the geotextile and screening is done. This process is continued for the beads of successively smaller diameter until percentage of glass beads passing through the geosynthetic exceeds 5 %. A grain size distribution curve is plotted and apparent opening size is read from this curve (size corresponding to 5 % passing).

2. Geogrid (G-1): Lattice shape is an index for showing the size of apertures, and it measures the distance between the centers of adjoining strands.

3. Geotextile and Geogrid (G-3): JIS L 1908.

(4) *Tensile strength (B-1)*

To evaluate the maximum tensile strength, tensile rigidity and stress strain relationship, a tensile test is conducted.

1. Geotextile and Geogrid (G-1, G-2, G-3):

Test equipment: Strain-controlled tensile tester

Test environment: Temperature → 23± 2℃

Humidity → 50± 20%

Test conditions: Refer Table 4.

(5) *Creep properties (B-2)*

Creep test is conducted to determine the elongation of the geotextile under the constant load for a long period of time.

1. Geotextile and Geogrid (G-1, G-2):

Test equipment: It should not have extraneous effects such as vibration during the test.

Test environment: Temperature → 23± 2℃

Humidity → 50± 20%

Test conditions: Refer Table 5.

(6) *Dynamic strength (B-3)*

Dynamic strength is the ability of geotextile to withstand repetitive loading before undergoing failure.

1. Geotextile and Geogrid (G-2):

(a) Momentary loads such as earthquakes:

A load of 30 % of the rupture strength is applied to 3 test samples of more than 30 cm long for 24 hours each and thereafter a load test is repeatedly conducted 3 times at a cycle below 1 Hz. The maximum load that will not result in rupture or generate strain of more than 15 % is determined.

(b) Train loads:

This test is conducted in a rigid box with geosynthetic embedded inside the soil. Loading is applied with the help of rigid plate of size 40 cm x 40 cm. Minimum loading level is maintained at 1.6 tf while cyclic load amplitude of 1.6 tf is applied at 20 Hz frequency and 1.5 million cycles are given. After the test, 10 test samples of geosynthetic are selected randomly and tested for tensile strength.

Table 4 Tensile test condition

	Test details	G-1	G-2	G-3
Geotextile	Test speed	1%/min (of the gauge length)	5%/min (of the gauge length)	20 ± 5%/min (of the gauge length)
	Width of specimen	20 cm or more	5 cm or more	(a) 5 cm or more (b) 20 cm or more
	Length of specimen between grips		30 cm or more	10 cm or more
Geogrid	Test speed	1%/min in the gauge length	5%/min in the gauge length	20± 5%/min in the gauge length
	Width of specimen	20 cm or more	Single strand	20 cm or more
	Length of specimen between grips		30 cm or more	20 cm or more
Geotextile and Geogrid	Number	5 pieces or more	20 pieces or more	5 pieces or more
	Test report	Calculate the tensile strength (kN/m)	Calculate the tensile strength (kN/m)	Calculate the tensile strength (kN/m)

Note : As per G-2, breaking strength is taken at Percent elongation of 15 (%) or less.

Table 5 Creep test condition

	Test details	G-1	G-2
Geotextile and Geogrid	Load steps	10–90% of tensile strength 5 steps or more	
	Test specimens	3 Pieces or more	3 pieces or more
	Test period	about 1000 hours	500 hours or more
	Length of specimen		30 cm or more
	Evaluation method	by Creep-Limit line chart.	by Elongation-Time line chart
Geotextile	Width of specimen	20 cm or more	5 cm or more
Geogrid	Width of specimen		One strand

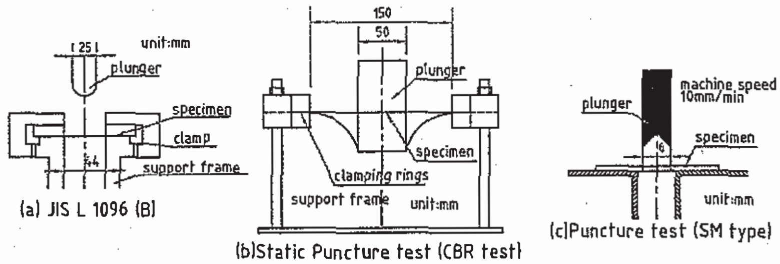

Fig.1 Examples of Test Apparatus

Table 6 Weathering test condition

(a) Outdoor exposure test

Time to begin the test	Select amongst March, April, September, and October
Exposure time	100-4000 hours
Number	5 pieces or more at each exposure interval

(b) Accelerated exposure test

Source of light kind	WS (Sunshine) type
Temperature of black panel	63±3°C
Spray cycle	18 minutes for 120 minutes
Exposure time	100-10000 hours
Number	5 pieces or more at each exposure interval

(7) *Breakage test (B-4)*

Reinforcements may get damaged by the impact of or due to the protrusion of rocks caused by the passage of heavy vehicles and/or construction machinery during the construction work. To determine the extent of damage to reinforcements due to such impacts or protrusions, a penetration test, a tear test and an impact test are conducted.

1. Geotextile and Geogrid (G-1):

(a) Puncture test: Breaking strength is tested by quasi-static penetration of rod against the reinforcement material via a compression testing machine (see Fig. 1).

(b) Tear test: The trapezoidal method recommended by JIS L 1908.

(c) Impact test: A rolling compaction test is conducted using the actual banking soil material to be used, and the resistance to damage is determined from the strength retention of the test samples after the test.

2. Geotextile and Geogrid (G-2):

(a) Impact test: Using a crusher run (C-40), 2m x 2m reinforcement material is laid covered by 30 cm depth of soil and then it is rolled over 4 times by a bulldozer, 2 times by a rammer and 6 times by a vibration roller. After digging the material out, samples are selected randomly and checked for damage and are compared with the original tensile strength.

(8) *Weather resistance (C-1)*

The strength of reinforcement material may deteriorate due to exposure to the natural conditions such as ultraviolet rays and cycles of dry and humid conditions due to climatic variations. To examine such effects, the outdoor exposure test and accelerated exposure test are conducted.

1. Geotextile and Geogrid (G-1):

(a)Outdoor exposure test: This test follows JIS L 1410 .

(b)Accelerated exposure test: This test follows JIS L 1415.

For details of these tests, refer Table 6.

(9) *Chemical properties (C-2)*

Both anti-acid and anti-alkali tests are conducted to determine the chemical resistance.

1. Geotextile and Geogrid (G-1): JIS K 7114 is followed.

Solutions used: refer Table 7.

2. Geotextile and Geogrid (G-2): Anti-alkali test.

More than 10 test samples are dipped in pH12 solution for 700 days at a curing temperature of 20℃ followed by a tensile test to evaluate the deterioration.

(10) *Biological resistance (C-3)*

To determine the extent of deterioration to the strength of reinforcements in soil caused by microorganisms, a bacteria resistance test is conducted.

1. Geotextile and Geogrid (G-1): Tests are conducted with reference to JIS Z 2911.

Table 7 Kind of soaking liquid for medicine test according to the environment

Medicine name→ / Soil condition ↓	Sodium chloride	Calcium hydroxide	Sodium hydroxide	Hydrochloric acid	Sulfuric acid
General condition A (pH = 6 - 8)	3.0%	0.01% pH = 11	0.01% pH = 11	0.01% pH = 3	0.01% pH = 3
General condition B (pH = 5 - 9)	3.0%	0.1% pH = 12	0.1% pH = 12	0.1% pH = 2	0.1% pH = 2
Special condition (pH ≤ 4, pH ≥ 10)	3.0%	Saturated solution	10%	10%	10%

2.4 *Design strength of individual reinforcements*

The design strength of the reinforcement is determined by applying partial factors of safety to the maximum tensile strength value of the reinforcement determined from the laboratory test (see Section 2.2(2) and 2.3(4)). Partial factors of safety are applied against the load conditions of actual design and according to the actual site conditions. Numerical values of these partial factors of safety are evaluated from the dynamic, creep, durability tests, etc., which are conducted as described in Section 2.2 and 2.3. The procedure to determine the design strength of reinforcements as suggested in various manuals is given below.

(1) *Metallic reinforcements*

All metallic reinforcements use materials according to the Japanese Industrial Standards with permissible stress to be taken directly as given in these standards.

1. Metallic strip (M-1) and Steel bar with anchor plate (M-2): Permissible stress for strips plated with zinc on materials confirming to JIS G 3101 is taken as 137 MN/m^2.

2. Grouted steel bar and metal others (R-M1): Materials as per JIS G 3122 are used and the permissible tensile stress given in this standard is adopted.

Example: SR 235 General strength 137 MN/m^2
In a corrosive environment 117 MN/m^2
SD 390 General strength 206 MN/m^2
In a corrosive environment 186 MN/m^2

(2) *Geosynthetic reinforcements*

Depending upon the guideline manuals, partial factors of safety for creep, durability, dynamic loads, etc., are applied on maximum tensile strength to obtain the design tensile strength.

1. Geotextile and Geogrid (G-1): Design tensile strength T_A is obtained as follows:

$$T_A = \frac{T_{max}}{F_{cr}\ F_D\ F_C\ F_B} \qquad (1)$$

Where, T_{max} = maximum tensile strength (as per G-1),
F_{cr} = safety factor for creep,
F_D = safety factor for durability,
F_C = safety factor for damage during construction work, and
F_B = safety factor for reduction of strength at joints.

2. Geotextile and Geogrid (G-2): For design of reinforced soil structures for railways, the design strength is determined for each load condition as given below:

General load $T_{AG} = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 . T_{max}$ (2)
Temporary load $T_{AT} = \alpha_1 \cdot \alpha_2 \cdot \alpha_5 . T_{max}$ (3)
Earthquake load $T_{AE} = \alpha_1 \cdot \alpha_2 \cdot \alpha_4 . T_{max}$ (4)

Where, T_A = design tensile strength,
T_{max} = maximum tensile strength (as per G-2),
α_1 = anti-alkali reduction coefficient,
α_2 = construction time reduction coefficient,
α_3 = creep reduction coefficient,
α_4 = momentary load reduction coefficient, and
α_5 = train load reduction coefficient.

3 TESTS FOR SOIL-REINFORCEMENT FRICTION BEHAVIOR

3.1 *Introduction*

To understand the behavior of reinforcement inside the soil, it is important to evaluate the friction and other interaction properties of reinforcement and the soil. Concepts and methods for evaluating these properties differ depending upon the purpose and design of reinforced earth structures as well as the kind of reinforcement used (see Table 8). In section 3.2, the basic testing method of JGS (1995.10) has been introduced which is used for evaluating the friction

Table 8 Evaluation of soil-reinforcement friction behavior

Code	Method of Design and Construction	Usage	Evaluation of friction behavior
(M-1)	Terre Armée Reinforced Retaining Wall	Wall Structure	The friction coefficient is evaluated from the test result
(M-2)	Multiple Anchored Retaining Wall	Wall Structure	The validity of the calculation is verified from the test result
(M-3)	Ground Anchor	Slope	As per detailed testing method (see Section 3.2)
(R-M1)	Multipile Reinforced Earth	Slope, Excavation	Details not given
(G-1)	Geotextile Reinforced Earth	Embankment, Wall Structure	Details not given
(G-2)	Reinforced Railroad/road with Rigid Facing Method	Wall Structure	Details not given
(R-G1)	As per JGS (1994.01)		As per detailed testing method (see Section 3.3)

properties of metallic reinforcements and soil for reinforced earth structures. The Geotextile Standardization Committee, Japanese Geotechnical Society, prepared a new draft of the Society's norm JGS (1994.01) for evaluating the friction properties of geosynthetic reinforcements and soil by direct shear and/ or pull out tests to be used in reinforced earth walls and banking structures. This has been introduced in Section 3.3.

3.2 *Ground Anchors*

As of this date, a pull out test for determining the value of the circumferential surface frictional resistance necessary for the design of reinforcements (grout material) for use in reinforced earth structures for stabilization of natural and artificial slopes has not been established and the rock bolt test method used in ground anchoring or the NATM (New Austrian Tunneling Method) is being used as a reference. This report introduces the basic test method as given in JGS (1995.10) and can be applied for soil nails, micropiling, dowelling, etc. The basic test refers to the testing conducted to understand the behavior and to evaluate the marginal pull-out strength of the anchor in reinforced earth structures, and to determine the various constants to be used in design of such structures.

(1) *Restriction and application*

In designing ground anchors, the marginal pull-out strength of anchors is defined as follows: "The marginal pull-out strength of anchors refers to the strength necessary to destroy an anchor when the anchor's ultimate destruction mainly depends on the condition of the ground. The ultimate pull-out strength shall, as a rule, be verified with a basic test, and a test shall be definitely conducted in the case of destruction of at least an important structure in the surroundings. The marginal pull-out strength of anchors differs depending upon the condition of the ground, the method of construction and the types of anchors used and hence tests shall be conducted under conditions close to the conditions in which the anchors will actually be used. If it is impossible to do so, the results of testing shall be applied to the design with due consideration to the difference in conditions."

The circumferential surface frictional resistance of the unit area of the anchor against the ground, based on which the marginal pull-out strength will be detennined, is calculated depending upon the kind of ground and its condition; however, since it differs from one construction method and anchor type to another, as a rule it is determined from the results of a basic test.

(2) *Basic test*

A basic test is conducted prior to the design. It is conducted to evaluate the frictional resistance and the marginal pull-out strength required for designing and examining the behavior of the anchor.

1. Apparatus

The equipment for the above test consists of pressurizing equipment, counterforce equipment and the measuring instruments. The test equipment should conform to the following specifications and be selected to suit the type of testing, the purpose, the maximum planned test load and the condition of the site.

(a) Pressurizing equipment

(i) It must have a nominal capacity of more than 1.2 times the maximum planned test load and be capable of maintaining a constant load for the specified duration.

(ii) It should also be capable of increasing or decreasing the load according to the planned load stages.

Note 1: Generally an oil pressure jack and an oil pressure pump are used as pressurizing equipment. In selecting an oil pressure jack, it should have sufficient capacity and stroke, and particularly for basic testing it should be

Table 9 Frictional resistance of anchor

Kind of ground			Frictional resistance (kgf/cm^2)
Bedrock	Hard rock		15 ~ 25
	Soft rock		10 ~ 15
	Weathered rock		6 ~ 10
	Mud stone		6 ~ 10
Gravel	N value	10	1.0 ~ 2.0
		20	1.7 ~ 2.5
		30	2.5 ~ 3.5
		40	3.5 ~ 4.5
		50	4.5 ~ 7.0
Sand	N value	10	1.0 ~ 1.4
		20	1.8 ~ 2.2
		30	2.3 ~ 2.7
		40	2.9 ~ 3.5
		50	3.0 ~ 4.0
Viscous soil			1.0 c (c : cohesion)

capable of loading 0.9 times of the tendon yield load. A further requirement is that the equipment should be capable of maintaining, increasing and decreasing loads smoothly at a constant speed, and it should be calibrated before use.

(b) Counterforce equipment

This should be strong enough to support the maximum planned test load and should not be any impediment to testing.

Note 2: The basic test is conducted by using a counterforce stake installed in a position outside the impact zone or by using a counterforce board and making a counterforce on the ground behind the counterforce board. In the method using a counterforce board, if the anchor body has shallow overburden, the counterforce may work as holding the load thereby breaking the ground behind the counterforce board, making it impossible to determine the true marginal pull-out strength. However, if test error can be minimized by properly choosing the overburden so as to reduce the effect of load holding, and by properly selecting the size, strength and rigidity of the counterforce board, it is possible to accurately measure the friction resistance between the anchor body and the ground, and accordingly this method is generally used.

(c) Measuring instruments

A load weight scale, a displacement meter and a timer, all of which should be verified as having the prescribed degree of precision.

Note 3: A load weight scale generally uses a Bourdon pressure gauge incorporated in pressurizing equipment or a load cell. The measuring precision of load cells may deviate depending upon the setting method. Hence, it is important to set them after making the surface smooth and to prevent the eccentric load.

Note 4: A displacement meter should have enough stroke to accommodate the expansion of the anchor, as otherwise it will require refilling which will impair the measuring precision. Therefore the maximum displacement must be accurately anticipated and a displacement meter should be selected to meet the maximum displacement. In a basic test, generally precision in the range of 0.1 mm is required. Attention should be paid so that the fixed point will not be displaced due to the load.

Note 5: As for timing devices, one conventional clock or watch for showing the standard time and one for measuring the time elapsed from the start of testing will be sufficient.

2. Conditions for testing

(a) For designing permanent anchors, a basic test should always be conducted.

(b) For designing temporary anchors, it is desirable to conduct a basic test.

Note 6: When planning and designing anchors, it is important to conduct a basic test to determine the various constants for use in design as well as the appropriateness of the anchoring method against the subject fixing ground and the structure. In view of its purpose, it is desirable for a basic test to be conducted before planning and designing, but in practice, it is difficult to do so because of the site conditions, and hence tests are usually conducted after starting the main construction work.

Nevertheless, the basic test should be conducted before the final review of the design so that the changes can be made on the basis of the basic test. In cases where temporary anchors do not heavy loads, or when anchors are fixed to a rock base, hard clay ground or dense sandy ground, a basic test may be omitted. When designing anchors without using a basic test, they must be designed according to Table 9, matching similar ground. The adequacy of the design must be verified with a suitability test as soon as possible after completing installation to verify whether or not the anchor design and installation are appropriate from the point of view of load-displacement properties by applying a load on the actual anchor to be used. For the following kinds of ground, it is desirable to conduct a basic test even for temporary anchors:

(i) Organic soil

(ii) Cohesive soil with a liquid limit > 50 %

(iii) Sandy soil of N value < 15.

3. Test anchors

Test anchors should be determined after considering the actual conditions under which they will be used. This includes the fixing ground for the anchor to be used in the basic test, anchor elements and the method of installation. However, the fixing length of the anchor and the sectional area of the tendon may be changed on the judgment of the head engineer.

Note 7: In many cases the frictional resistance of anchors varies depending upon anchor elements and method of installation. Hence it is desirable that the anchor used for basic testing is as close as possible to the anchor actually

Table 10 Maintenance time of load

Soil type → / Nature of load ↓	Viscous soil	Sandy soil	Bedrock	Note
When virgin load	Constant load of 15 minutes or more	Constant load of 10 minutes or more	Constant load of 5 minutes or more	However, if displacement is not steady, load is maintained until displacement stabilizes.
When load in the Stress history	Constant load of 3 minutes or more	Constant load of 2 minutes or more	Constant load of 1 minute or more	

used. If the fixing ground for the anchor, the anchor type, the diameter of the drilled hole and the method of drilling the hole vary, tests should be conducted for each different combination of factors. But, for example, if a test is conducted with an anchor element of the same fixed length as the real anchor, the maximum planned test load may become large, and this would require large test equipment and would make testing difficult. In such a situation when an exact matching test of a large anchor is conducted, it may not be possible to maintain the load under the restriction of the permissible tensile strength of the tendon until the anchor body can be pulled out, so in some cases the marginal pull-out strength can not be determined. In such a case, the test should be conducted by shortening the anchor body fixing length or increasing the sectional area of the tendon according to the judgment of the head engineer. When conducting a basic test by shortening the anchor body fixing length and applying the result thereof to a longer fixing length, there is a possibility of overestimating the per unit area friction resistance, so it is necessary to make sufficient studies in this respect. Assuming, for example, the marginal value of the circumferential friction resistance (circumferential friction strength) distributed around the body of a stretch type anchor is constant without any relation to the anchor fixing length, the marginal pull-out strength (T_{ug}) of the anchor can be calculated by the following formula with the anchor body fixing length (l_A) as a variable:

$$T_{ug} = \frac{E \cdot A \cdot \alpha}{k_s} \cdot \tau_{ug} \cdot \tanh(\alpha \cdot l_A) \quad (5)$$

$$\alpha = 2 \cdot \sqrt{k_s/(E \cdot D)} \quad (6)$$

$$E = (E_C \cdot A_C + E_S \cdot A_S)/A \quad (7)$$

$$A = A_C + A_S \quad (8)$$

Where,

τ_{ug} = marginal value of the circumferential friction resistance,
T_{ug} = marginal pull-out strength of the anchor,
k_s = counterforce coefficient of the shearing ground,
E_c = elasticity coefficient of the ground,
A_c = sectional area of the anchor body,
E_s = elasticity coefficient of the tendon,
A_s = sectional area of the tendon, and
D = diameter of bore hole.

As for the tendon, its sectional area should be determined so that a load can be maintained until the anchor body can be pulled out. It is also important that the strength and rigidity of the counterforce equipment is checked.

4. Method of loading and items of measurement

(a) The initial load should be approximately 10 % of the maximum planned test load.

(b) The load should be divided into 5 to 10 stages between the initial load and the maximum planned test load, with load control to be conducted in multiple cycles. When the marginal pull-out strength can not be confirmed even at the maximum planned load, load should be increased until pull-out is achieved, after first reducing the load down to the initial load. However, loading should not exceed 0.9 times of the yield load of the tendon.

(c) The load in each cycle should be maintained at a constant value for the times shown in Table 10.

(d) The following items should be measured at each load stage:

(i) Load
(ii) Amount of displacement
(iii) Time

Note 8: The maximum planned test load should be determined with reference to the value of the circumferential friction resistance of the anchor body against conventional similar ground. However, the difference between maximum planned load and actual load may vary up to two times and hence the tensile strength of the tendon should be appropriate. Loads should be applied as shown in Fig. 2 according to a multi-cycle method to determine the relationship between the load, residual displacement and the amount of reversion of elasticity. It is also desirable to have as many load stages as possible to upgrade the precision of testing. Where the marginal pull-out strength cannot be confirmed even at the maximum planned test load, loading should be conducted in increasing load stages until the anchor body can be pulled out, but not exceeding

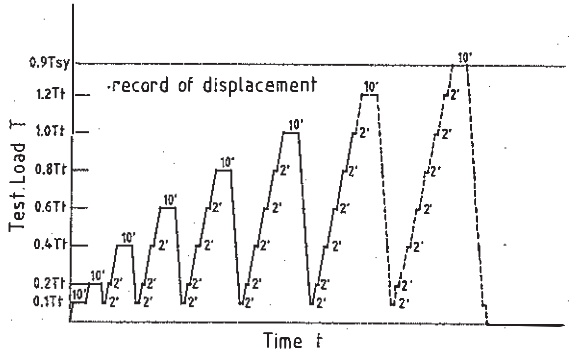

Fig. 2 Planning Chart of Loading

Table 11 Load speed (constant)

During loading	Planned maximum test load / 10~20	tf/min
During unloading	Planned maximum test load / 5~10	tf/min

0.9 times of the yield load of the tendon. Furthermore, the load should not be increased or decreased rapidly, but at a nearly constant speed. Table 11 should be used as a guide for loading speed. For judging whether or not displacement has stabilized at each load stage, it is convenient to plot the amount of displacement per minute. Guidelines such as those given in Table 12 are being used as standards in some other countries.

From the results of conventional testing, generally a change of less than 1 mm of the amount of displacement during the last 3 minutes of load retention may be used as a guideline for stable displacement.

Where there is more than 1 mm change in the amount of displacement, the load should be retained for an additional 1 minute, and load retention should be continued until the condition that change in displacement during the preceding 3 minutes is less than 1 mm/3 minutes is satisfied. Also, while under load, the amount of displacement of the anchor head and the amount of displacement of the counterforce equipment in each load stage should be measured after every 1 minute. While unloading, the approximate value of the amount of displacement of the anchor head should be measured at each of the load stages.

5. Summary of test results and judgment

(a) The load on the anchor head-displacement curve, the load-elastic displacement curve, and the load-plastic displacement curve should be plotted.

(b) The tendon free length and the tendon friction loss are obtained from the load-elastic displacement curve.

(c) The marginal pull-out strength is obtained from the load-plastic displacement curve. However, where the maximum test load does not reach the marginal pull-out strength, the maximum test load is deemed to be the marginal pull-out strength at the time of design.

Note 9: The results of the tests should be summarized, as mentioned above, in the form of load-displacement curves. The displacement should be divided into elastic displacement (δ_e) and plastic displacement (δ_p), and should be plotted in the form of a load-elastic displacement curve and a load-plastic displacement curve; Where δ_p is the amount of residual displacement at the point where unloading was reduced to the initial load, and de is the total amount of displacement δ_c at each load stage minus δ_p. The marginal pull-out strength is the load where the load-plastic displacement curve in Fig. 3 completely turns downward; however, generally the maximum value of the test load where the amount of displacement stabilizes may be deemed to be the marginal pull-out strength. When the anchor body cannot be pulled out, the shield load of the tendon is deemed to be the marginal pull-out strength. The amount of friction loss is calculated as the balance between the initial load and the cross point of the load coordinate (coordinate T) and the extension of the straight line portion of the load-elastic displacement curve (see Figs. 3 and 4). The free length of

Table 12 Different standards for steady displacement

Name of Standard	Permissible valuc	Observation time
DIN	0.5 mm or less	for 15 minutes from 5 minutes
PTI	1.0 mm or less	For 10 minutes from 1 minutes
SIA (Schweizer Norm)	2% or less of δ_e	For 5 minutes from 0 minute (rock and sandy soil) For 15 minutes from 0 minute (Ground with little cohesion and Over consolidated clay)
BSI	5% or less of δ_e	For 15 minutes from 0 minute

Note 1 : displacement is considered as steady if the amount of displacement of anchor head during observation time is within the permissible value.
Note 2 : Point of time after which the load was maintained almost constantly is called 0 minutes in the observation time.
Note 3 : δ_e = Elastic displacement of anchor head

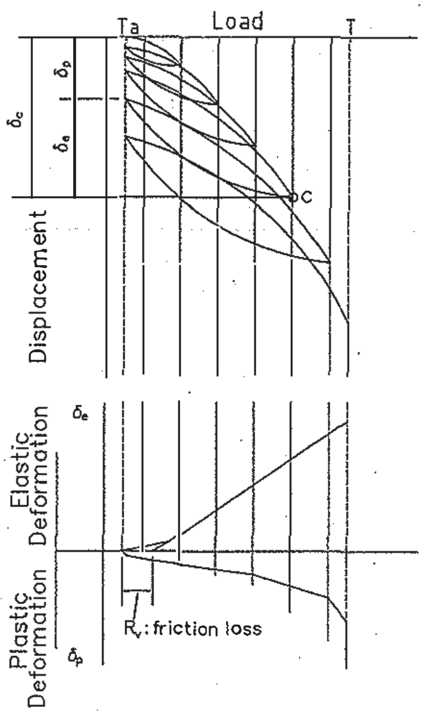

Fig. 3 Load-displacement curve

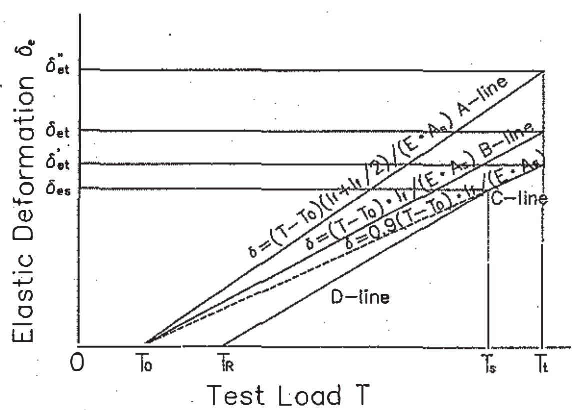

Fig.4 Evaluation Diagram

the tendon is obtained from the slope of the straight line portion of the load-elastic displacement curve, and is calculated according to the following formula:

$$l_{sf} = k \cdot E \cdot A_S = \Delta\delta_e / \Delta T \cdot E \cdot A_S \qquad (9)$$

Where, l_{sf} = free length of the tendon,
k = the slope of the straight line portion of load-elastic displacement curve,
E = Young's modulus of elasticity of the tendon, and
As = the sectional area of the tendon.

3.3 *Soil-geosynthetic friction behavior*

(1) *Introduction*

JGS (1994.01) describes the testing procedures for measuring the frictional resistance of geosynthetic to soil. The standard test methods consist of a direct shear test for determining the interface friction parameters, c_s and δ_s and a pull-out test for determining the pull-out friction parameters, c_p and δ_p, where c and δ refer to the adhesion and angle of friction, respectively. The test results obtained by direct shear test or pull-out test can be used in the design of geosynthetic reinforced soil structures (also see Hayashi et al. (1994)). The total frictional resistance of geosynthetic embedded in soil may be a combination of sliding, rolling and interlocking of soil particles and geosynthetic surfaces and shear strain within the geosynthetic specimen. Hence, the frictional properties of a geosynthetic can be expressed only with reference to the soil material and geosynthetic used in the testing. Therefore tests should be performed under site-specific soil conditions. The tests are applicable to a wide variety of geosynthetics such as geowoven, geononwoven, geoknit, geogrid and other geotextile related products. In general, the direct shear test can be used for a geosynthetic that separates the soil such as

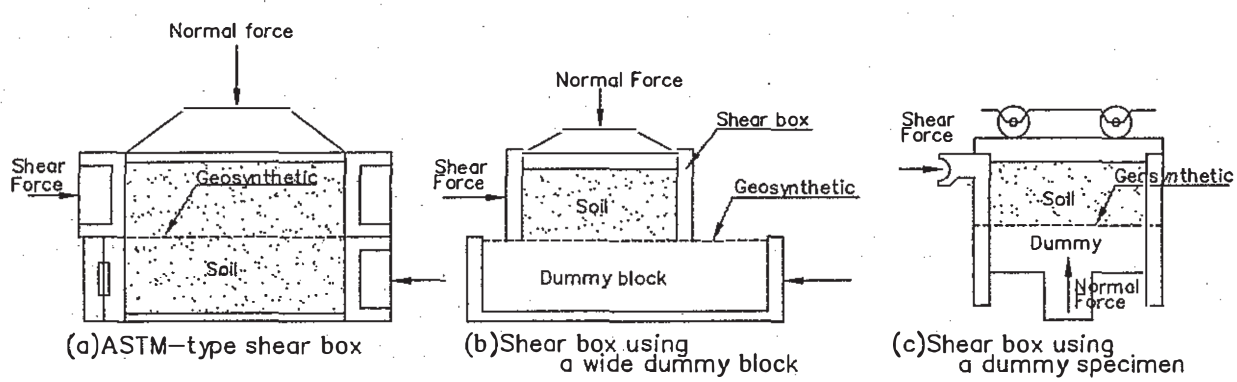

Fig. 5 Examples of Shear Box

geowoven, geononwoven and geoknit, and that develops a necking under the tensile force, such as geonet. The pull-out test is applicable to a geogrid through which super and sub-stratum soil is continuously in contact. Both tests should be conducted at a temperature of 20 ± 5℃ and a relative humidity of 50 ± 5 %. Direct shear test and pull-out test are described in Section 3.3 (2) and 3.3. (3) respectively in this report.

(2) *Direct shear friction test*

1. Apparatus

(a) Shear box: The size should be large enough in comparison with both the maximum soil particle size and the opening size of geosynthetic being tested.

Note 1: A rectangular container is recommended for geogrid and geonet. Placing more than four ribs of specimen are required in the shearing direction. The examples of the shear boxes are shown in Fig. 5.

Note 2: For a large shear box (more than 10 cm in thickness), their side walls should be coated with a silicone grease and a thin latex rubber membrane should be used to reduce the wall friction.

Note 3: A rigid dummy spacer such as wooden block may be placed either in the upper or the lower shear box.

(b) Normal stress loading device: It should be capable of applying a normal confining pressure up to 200 kPa.

(c) Shear force loading device: It must be capable of applying a horizontal shear to the specimen at a constant rate of displacement, and of moving more than 15 % of the length or the diameter of shear box.

(d) Force measuring devices: They should have an accuracy of ± 1 % of the maximum shear or normal forces.

(e) Displacement indicators: They must be capable of measuring normal and horizontal deformations of the specimen to an accuracy of ± 0.1 mm.

(f) Compaction rammer: A rammer by which the soil is compacted in the container.

(g) Multi-sieve device: For testing dry sands, this device can be used in such a manner that the height of multi-layered sieves, of which the opening sizes are 3 to 5 times larger than the maximum grain size of soil, is controlled to produce the required density of the soil specimen.

2. Preparation of test specimens

(a) The maximum soil particle size must be less than 1/10 of the height of shear box.

(b) The moisture content of the soil used in the test should be adjusted during compaction.

(c) A uniform soil specimen at the required density is prepared by multi-sieving method for dry sands or by a rammer compaction method for other soils.

(d) Prepare a geosynthetic specimen having sufficient size to facilitate clamping and testing. For an anisotropic material, a minimum of five specimens shall be taken in each direction.

(e) When geosynthetic is to be used in the wet or submerged condition and is anticipated to get changed in its strength, size, surface texture or other properties, put the specimen in the wet atmosphere or soak it in water for minimum 24 h prior to the testing.

Note 4: For specimens tested in the saturated state, leave the wetted specimen for 15 min. and then place it in a shear box within 30 min.

(f) Assemble the shear device after compacting the soil and placing the geosynthetic in the testing box.

Note 5: In the case of using a dummy block, gluing or clamping of the geosynthetic specimen to dummy substratum is an acceptable technique.

The examples of fixing methods are given in Fig. 6. To maintain the sufficient friction, coarse sand is adhered to the surface of block.

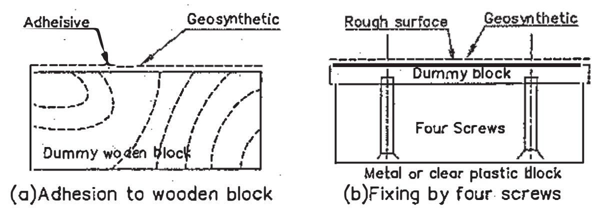

Fig. 6 Examples of Fixing method of geosynthetic

3. Test procedure

(a) Apply the normal compressive stress, σ_n to the soil specimen.

(b) Record the normal displacement, ΔH, during the compression.

Note 6: For coarse grained soils, the compression may be finished in 10 min.

Note 7: Compression time can be estimated in the following manner: After determining the most steep tangent line of ΔH-log t curve plotted in the semi-logarithm graph, the line is slid in parallel 3 times on the time axis, and the compression time is given as the intercept of the line versus ΔH-log t curve.

(c) After the compression, the shear test is conducted using a constant rate of displacement. In the absence of any specification, a standard displacement rate of 1 mm/min. is used.

(d) Record the shear force as a function of displacement and run the test until the shear measuring device shows a peak value, or until the shear displacement reaches 15 % of the length or diameter of shear box.

(e) At the end of the test, moisture content of the soil specimen is determined.

(f) In this manner, several tests at different normal compressive stress each with new specimen are conducted.

4. Calculations

(a) Plot the test data as a graph of apparent shear stress calculated for each recorded value of shear force versus horizontal displacement.

(b) Plot applied normal stress σ_n, versus maximum shear

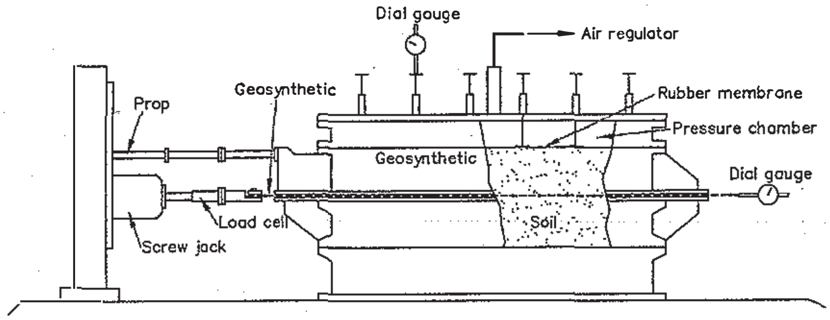

Fig. 7 An example of pull-out test apparatus

frictional strength, τ_{Smax}, for each test conducted.

(c) Connect the data points with a best fit straight line using the following equation, and determine the shear friction parameters (c_S, δ_S) of the soil-geosynthetic interface.

$$\tau_{S\max} = c_S + \sigma_n \tan\delta_S \qquad (10)$$

(3) *Pull-out test*

1. Apparatus

(a) Pull-out test apparatus: The size of the upper and lower boxes must be larger than 30 cm in width (B_B), 30 cm in length (L_B), and 20 cm in height.

Note 8: A typical layout of the apparatus is shown in Fig. 7. For reducing the wall friction, the same procedure may be followed as described in 3.3 (2) 1 (a) Note 2.

(b) Normal stress loading device: as directed in 3.3 (2) 1 (b). A rubber pressure bag is used as a standard loading device.

(c) Pull-out device: It should be capable of moving about 20 % of the length of the box, at a constant rate of displacement. The standard displacement rate is 1mm/min.

(d) Clamping device: It must be wide enough to hold the whole width of specimen, and able to apply the uniform pull-out stress to a specimen without sliding or any damage.

(e) Pull-out force measuring device: It should have an accuracy of ± 1 % of the tensile breaking strength of geosynthetic used in the test.

(f) Displacement indicators: as directed in 3.3 (2) 1 (e).

(g) Miscellaneous equipment: Wires and guide-tubes for measuring elongation of geosynthetic specimen.

Note 9: Friction between a wire and soil may be reduced using a guide-tube. A stainless steel wire of about 0.2 mm in diameter and thin flex or metal guide-tube is recommended.

(h) Compaction rammer: as directed in 3.3 (2) 1 (f).

(i)Multi-sieve device: as directed in 3.3 (2) 1 (g).

2. Preparation of test specimens

(a) A soil specimen is prepared in a similar way as described in 3.3 (2) 2 (a) to (c).

(b) Prepare a geosynthetic specimen having a slightly short width than that of pull-out test box, and having length in general at least 20 % longer than that of test box. In the case of the apparatus in which the rear of a geosynthetic specimen is unable to be hung down to the outside, prepare a specimen at least 1.2 times longer than the limit length of pull-out resistance mentioned in 3.3 (3) 4(d). For an isotropic material, a minimum of five specimens shall be taken in the same direction.

(c) When the geosynthetic is to be used in the wet or submerged conditions, a specimen is prepared in a similar way as described in 3.3 (2) 2 (e).

(d) After compacting the soil in the lower box, a geosynthetic specimen is placed on the soil and connected to the clamps. A wire covered with a guide-tube is tied at each position for measuring its elongation and drawn out towards its rear side. Then compact the soil in the upper box.

Note 10: It is desirable to select five or six measuring positions at regular intervals within the box, and two positions at the front of specimen. Examples of measuring the elongation are shown in Fig. 8.

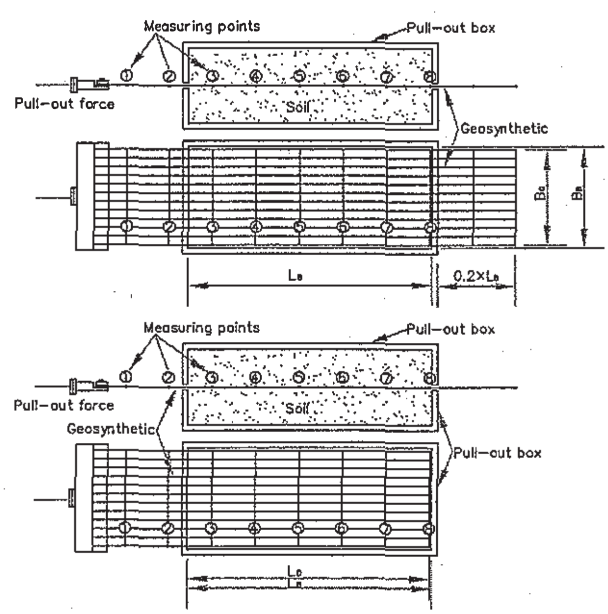

Fig. 8 Examples of measuring points of displacement

3. Test procedure

(a) The compression process of soil specimen is the same as directed in 3.3 (2) 3 (a) to (c).

(b) After the compression, a pull-out test is carried out at the constant rate of deformation.

(c) Record pull-out force, F_T, and displacement, X_i, at each measuring point under a constant normal stress, σ_n.

Note 11: A normal displacement shall be recorded during the test.

(d) The pull-out test should be conducted until the strain at the clamping reaches 20 % or until the break failure of the geosynthetic.

(e) At the end of the test, determine the moisture content of the soil specimen.

(f) In this manner, tests at different compressive stresses for more than four new specimens are conducted.

4. Calculations

(a) A pull-out force distribution in the box can be considered as shown in Fig. 9(a), where T_i' is a resistance of longitudinal rib between nodes.

Therefore a resultant force at each node, $T_i = T_i' + \tau_{ij}$ x node interval, can be determined as shown in Fig. 9(b).

Note 12: For geosynthetics without nodes, any point selected arbitrarily can be taken as a node.

(b) The distribution of elongation, X_i, and strain, ε_{ij}, can be obtained from the measured displacements at each node, as shown in Fig. 9 (c) and (d).

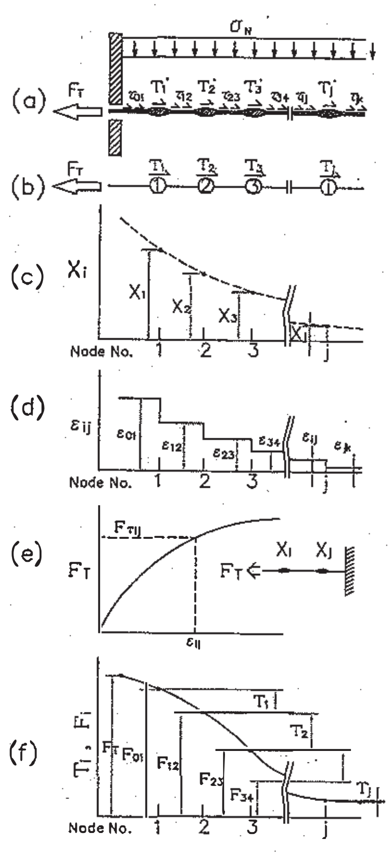

Fig. 9 Procedures of pull-out test data analysis

(c) As shown in Fig. 9 (f), the tensile force, F_{ij}, corresponding to the strain, ε_{ij}, can be estimated from an index stress-strain curve shown in Fig. 9 (e), which is obtained by testing the geosynthetic under no lateral confining pressure.

(d) A limit length of pull-out resistance, L_T is given by the following equation:

$$L_T = \frac{F_U}{2(c + \sigma_n \cdot \tan\phi)} \tag{11}$$

where, F_U = breaking strength of geosynthetic (kPa),
c = apparent cohesion of soil (kPa), and
ϕ = angle of shearing resistance of soil

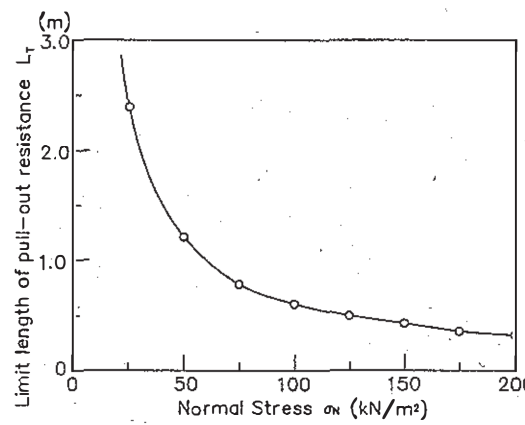

Fig. 10 An example of limit length of pull-out resistance vs. normal stress

Note 13: The relation between the limit length of pull-out resistance and the normal stress for Toyoura sand is shown in Fig. 10.

(e) The effective length of pull out resistance, L_E, and the maximum effective force of pull out resistance, F_{TE}, are defined as follows:

(i) In the case that the geosynthetic was entirely pull-out with no breaking:

$$L_E = L_B \quad \text{(the length of pull-out box)} \tag{12}$$

$$F_{TE} = F_{Tmax} \quad \text{(the maximum pull-out force)} \tag{13}$$

(ii) In the case that the geosynthetic was pull out associated with breaking or that the elongation of geosynthetic reached almost 20 % of the length of pull-out box but no movement of the rear part of geosynthetic occurred:

$$L_E = L_T \tag{14}$$

$$F_{TE} = F_{Tmax} - F_R \tag{15}$$

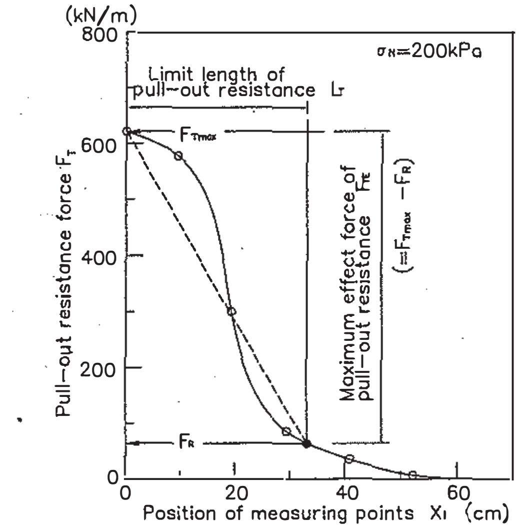

Fig. 11 An example of determining maximum effective force of pull-out resistance

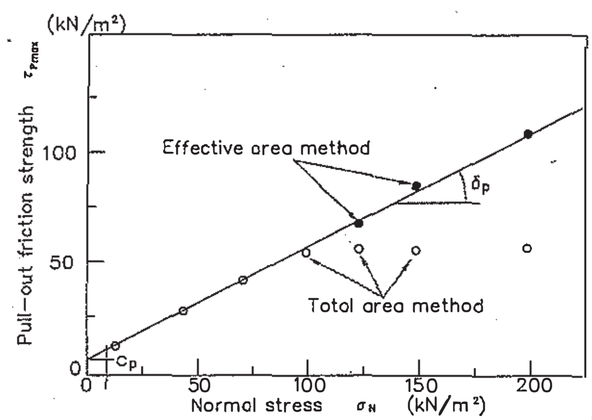

Fig. 12 An example of determining pull-out frictional parameters

where, F_R = The pull-out force generated at the rear outside of the limit length of pull-out resistance.

Note 14: The method (i) and (ii) above are called as total area method and the effective area method respectively.

Note 15: An example of calculating the maximum effective force of pull-out resistance, F_{TE}, is shown in Fig. 11.

(f) The pull-out frictional strength, τ_{pmax}, is expressed by the following equation:

$$\tau_{p\max} = \frac{F_{TE}}{2 \cdot L_E} \qquad (16)$$

(g) The pull-out friction parameters (c_p, δ_p) of geosynthetic in the soil are given as follows:

$$\tau_{p\max} = c_p + \sigma_n \cdot \tan\delta_p \qquad (17)$$

Note 16: An example for calculating the pull-out frictional parameters is shown in Fig. 12.

4 CONCLUSIONS

This report presents both index tests as well as the tests for evaluating the interaction behavior between soil and reinforcement as recommended by different Japanese institutions. Test items on both metallic as well as geosynthetic reinforcements have been discussed. Index tests are covered through relevant standards, reports and manual references. To evaluate soil-reinforcement interaction behavior, a basic test for metallic reinforcements and a direct shear and pull-out test for geosynthetic reinforcements have been described.

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JIS G 3191	*Shape, dimension, weight and tolerance for hot rolled steel bar and bar-in-coil*
JIS G 3193	*Dimensions, mass and permissible variation of hot rolled steel plates, sheets and strip*
JIS G 3536	*Uncoated stress-relieved steel wires and strands for prestressed concrete*
JIS K 7114	*Method of testing chemical resistance properties of plastics*
JIS L 1410	*Outdoor exposure test for plastic construction materials*
JIS L 1415	*Accelerated exposure test of plastic construction materials*
JIS L 1908	*Test methods for geotextiles*
JIS Z 2241	*Method of tensile test for metallic materials*
JIS Z 2271	*Method of tensile creep test for metallic materials*
JIS Z 2272	*Method of tensile creep rupture test for metallic materials*
JIS Z 2371	*Methods of neutral salt spray testing*
JIS Z 2911	*Method of test for fungus resistance*