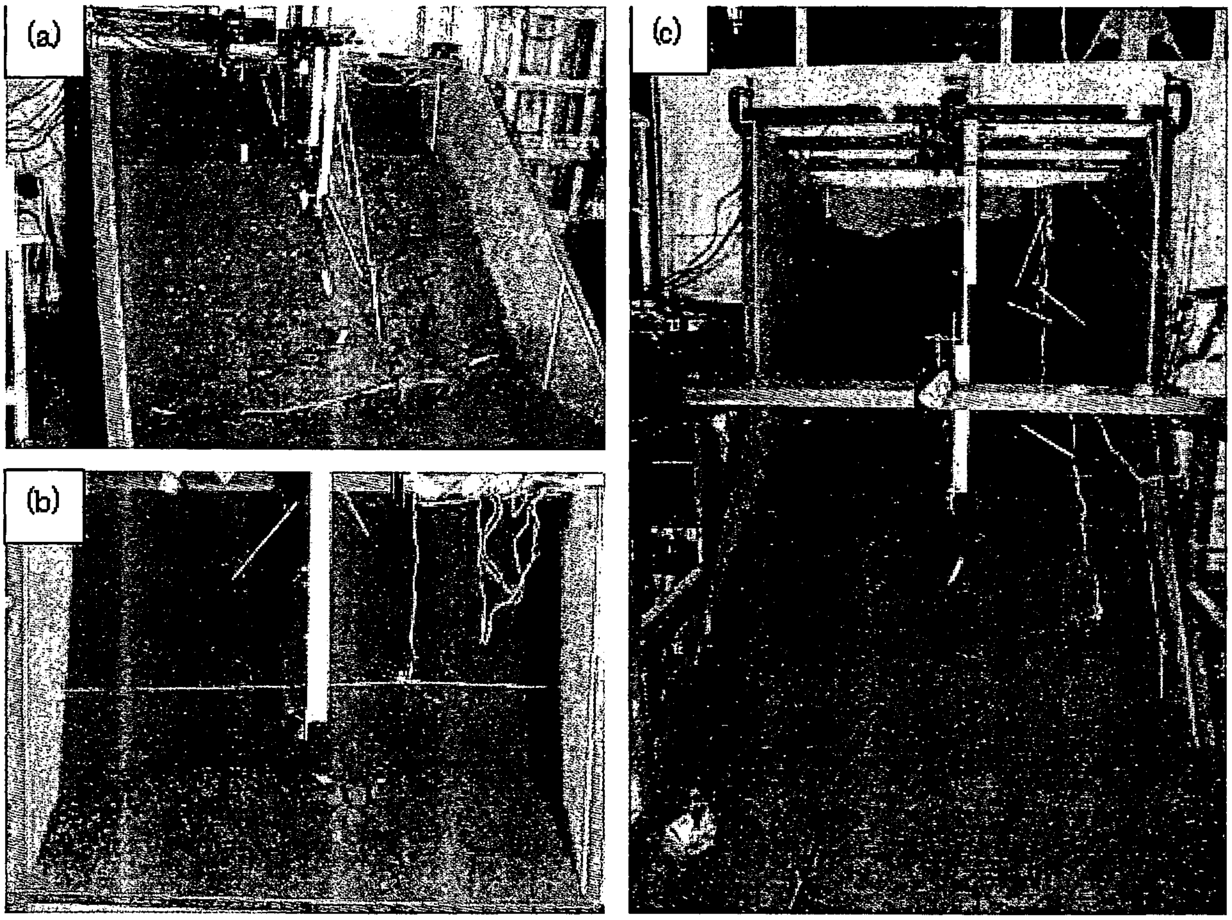

Photo 6 Test models after failure (a) Slope-I-3, (b) Slope-V-1 and (c) Slope-V-2

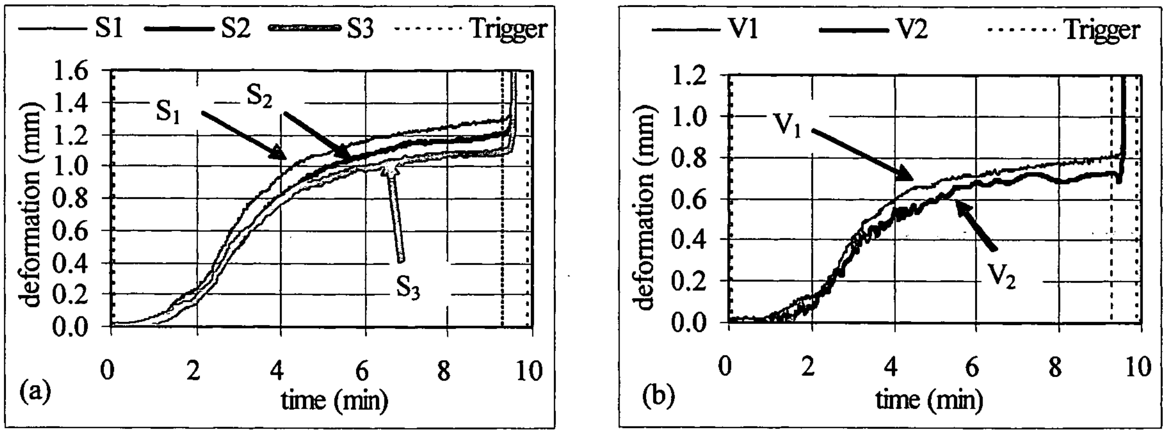

Fig. 6 Deformations measured with laser (a) on the slope and (b) on the top surface of the slope

RESULTS AND DISCUSSION

Cases of collapsed models; Slope-I-3, Slope-V-1 and Slope-V-2 are shown on Photos 6(a), (b) and (c), respectively. In the Figs. 6(a), (b) and (c), deformations measured by the laser sensors for Slope-I-3 test model are shown. Trigger in each figure represents the start and the end of the excavation steps. This is same for all the test model results. Trigger line represents the start and end of each step. Exceptionally, in Figs. 6 and 7, first step included the interval time also. As

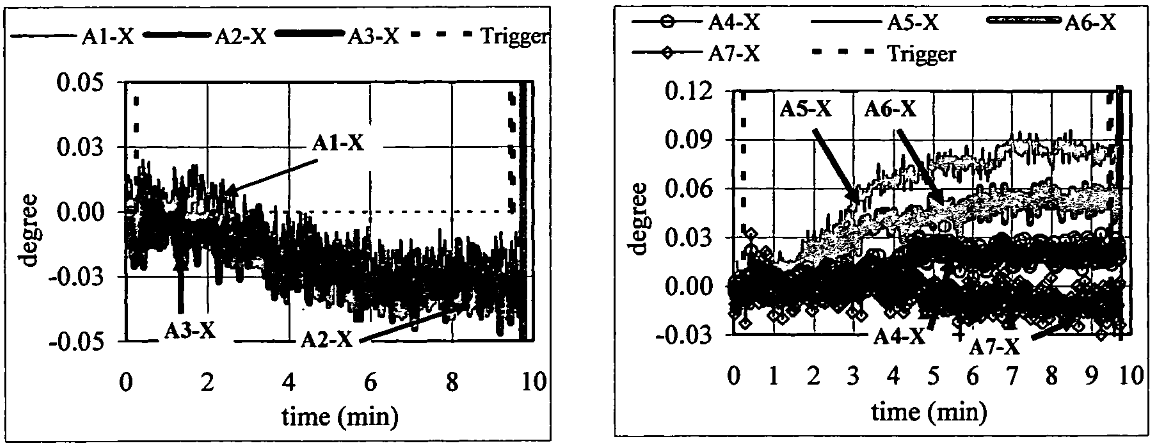

Fig. 7 Measurement of tilt-sensor (a) on the slope and (b) on the top surface (X-direction only)

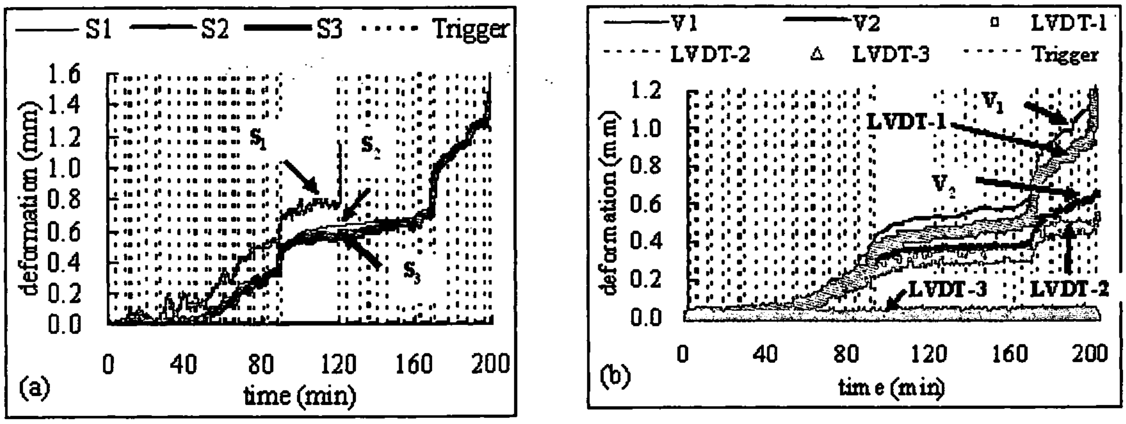

Fig. 8 Deformations measured by tilt-sensor for Slope-V-1 (a) on the slope and (b) on the top

seen in the figures, deformations gradually increased during the excavation of trench and reached almost constant value during the resting time. But during the start of toe excavation, there was a sudden increase in the deformation and slope was failed. Here, S_1, V_1 and H_2 showed the largest deformation. In Figs. 7(a) and (b), change in the angle along the X-direction due to the movement of slope and deformation of top surface for Slope-I-3 is shown. Along Y-direction, there was a slight change in the angle (not shown here). As shown in the Figs. 6(a), (b) and (c), here also change in the angle gradually increased during the trench excavation and reached almost constant value during the resting period. But as soon as the toe excavation was started, there was a sudden increase in the angle showing the complete failure. Tensile crack was seen just on the line of A5 and A6 tilt-sensors. Although the amount of change in the angle of A4, A5, A6 and A7 varied to some extent, A5 and A6 which were on the crack line showed the larger angles. Comparing the results of Figs. 6 and 7, similar trend of the deformations and changes in the angle with the time of excavation (steps) could be seen.

Deformations of slope and top surface (vertical) measured with laser and LVDTs for Slope-V-1 are shown in Figs. 8(a) and (b), respectively. In Fig. 8(a), data of S_1 and S_2 are cut off during the measurement. The reason behind this is that the excavations were done at their positions also. In Fig. 8, rapid deformations were seen at 12^{th} step (round 89 min., up to the bottom of the slope), 18^{th} step (round 169 min., up to the bottom of the slope) and 21^{st} step (round 197 min) excavation steps. After 197 min. of excavation, change in the deformation values become too

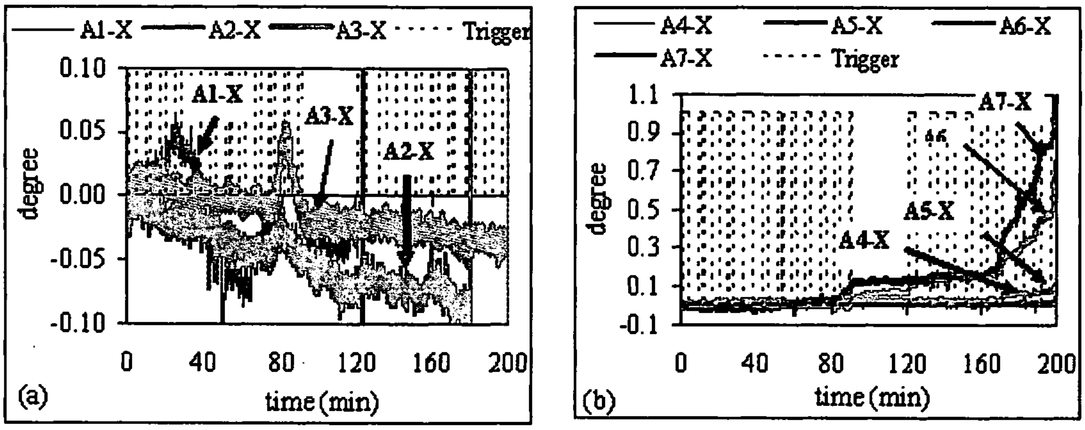

Fig. 9 Measurement of tilt-sensor (a) on the slope and (b) on the top surface (X-direction only)

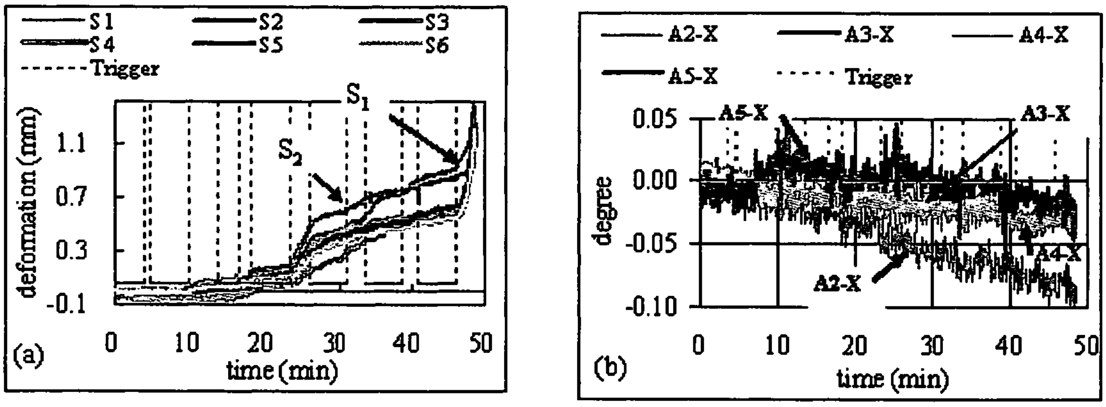

Fig. 10 Measurement on the slope (Slope-V-2) (a) from the laser sensor and (b) from the tilt-sensor

steep and the slope was failed. In Figs. 9(a) and (b), the change in the angle with tilt-sensors which are inserted at the same position near the targets of the laser is shown. Fig. 9(a) showed the movement of tilters placed on the slope (A1, A2, A3, etc.) and Fig. 9(b) showed the changes in angle measured on the top surface of the slope (A4, A5, A6 and A7), respectively along the X-direction. Data of A1 and A2 were cut-off during the excavation. This is due to the reason that the positions of tilt-sensors were encircled within the excavation area with the progress of excavation. Comparing the results of tilt-sensors (change in angles with time), laser and LVDT (the measured deformation data with time), similar trend could be seen. In this test, the changes in angle on the top surface is larger than those on the slope. Here, tensile crack has developed between the A4, A6 and A5, A7 tilt-sensors. There might be some relations between the location of the sensors and the positions of failure crack which may change the measurement data. As seen in the Fig.9 (b), A4 and A6 show small change in angle whereas A5 and A7 showed a large change in angle. This means measurement data are also dependent upon the positions of sensors set up.

Deformations and angles (along X-direction) measured from the laser sensor and tilt-sensor respectively, on the slope for Slope-V-2 test are shown in Figs. 10 (a) and (b). With the time and steps of excavation, increased in the deformations could be seen in Fig. 10 (a). Similar trends in the change of angle along the X-direction for the tilt-sensor are shown in Fig. 10 (b) although there are noises during the measurement. In this test, the tensile crack was developed behind the

A6 and A7 which made it difficult to compare the result with that of Slope-V-1 test.

CONCLUSIONS

From the small size full scale tests, following conclusions could be withdrawn;
1. With the step and time of excavation, deformations of the slope and top surface of the slope could be measured from the start to the end of the excavation. Steep increase in the deformation slope just before the failure was able to measure.
2. Tilt-sensor also gave the gradual response with the time and step of excavation. Sharp change in the angle before the failure could also be measured.
3. Similar trend of deformation as well as change in angle was observed. Hence the applicability of tilt-sensor in the field is possible.

ACKNOWLEDGEMENT

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Development of a New Soil Tensile Strength Test Apparatus

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Abstract

This paper describes a newly developed apparatus for measuring the tensile strength of compacted and pre-consolidated saturatedsoft to medium clayey soils. This apparatus is simple to use to perform a soil tensile strength. Two types of tensile molds are described and results obtained from them are compared. Repeatability of test results is also verified. Effects of water content, dry density, proportions of particle size and amount of fines present in the soil are also examined. Tensile strength and unconfined compression test results are compared. It was found that the ratio of unconfined compression strength (q_u) to tensile strength (q_t) for statically compacted Kanto loam soil is around 12.5. In case of compacted Kanto loam, maximum value of q_t and q_u is obtained around 50~60% of water content for all the samples prepared at three different dry densities (ρ_d = 0.66, 0.68 and 0.7 g/cm^3). Both types of strength decrease on wet and dry sides of this maximum value.

In case of mixtures of NSF clay, silt and sand in different proportions, it is observed that with the increase in the amount of finer particles, both q_t and q_u increase. But with the increase in the size of finer particles, reduction in the strengths is observed.

In case of pre-consolidated saturated NSF clay, tensile and unconfined compression tests are performed. Saturated NSF clay samples are prepared under the pre-consolidation stresses of 100, 200 and 300 kPa. The ratio of strength (q_u/q_t) obtained for this saturated NSF clay is around 6.

Introduction

In order to understand the development of tensile crack which leads to the failure of slopes, earth dams, embankments, pavements and ice lens development process during the freezing of soils, it is necessary to know the exact value of tensile strength that the particular soil exhibits. The development of a simple and appropriate method for the determination of tensile strength in the laboratory is necessary. In the past, tensile strength of soils has been generally neglected. Because tensile strength of soils, especially soft and saturated ones, is considered to be zero or relatively very small in comparison to compressive strength. Furthermore it is difficult to measure the tensile strength directly in the laboratory. Several methods of tensile testing of soils such as uniaxial direct tensile test (Tschebatorioff et al., 1953), a simple

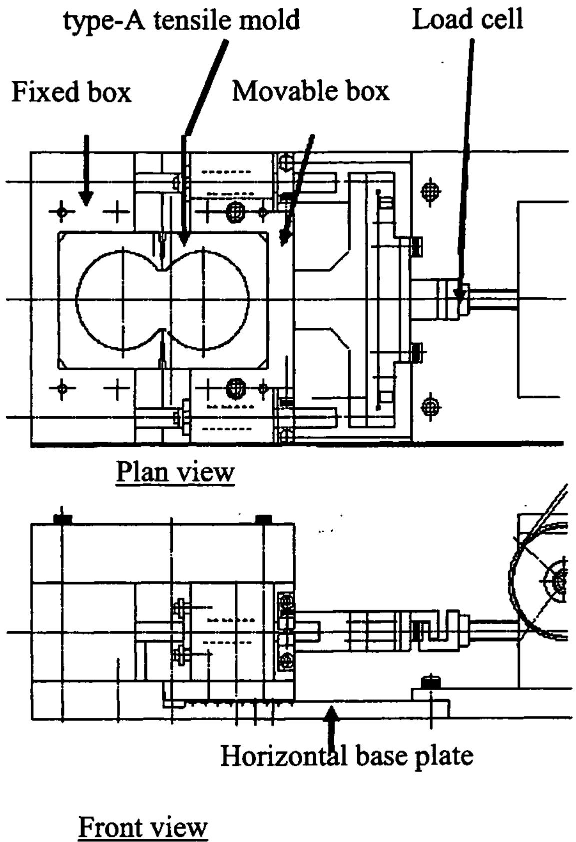


Figure 1. Outline of tensile test apparatus with type-A mold.

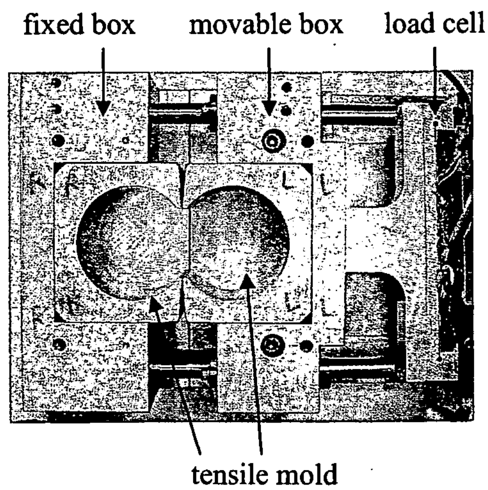


Photo 1. Apparatus with type-A tensile mold.

splitting test (Tang et al., 2000), unconfined penetration test (Fang et al., 1981), flexure (beam) test (Ajaz et al., 1975), indirect Brazilian test (Krishnayya et al., 1974), hollow cylinder tests (Mosaid, 1981), etc., have been used in the past. Due to the limitations in the test methods, the earlier tests were only focused on to the more brittle and elastic materials (stiff, compacted and soil cement mixes) having higher tensile strength rather than for ductile materials (soft, saturated and clayey soils) having lower tensile strength. Most of the earlier researches are applicable to unsaturated soils rather than saturated soft soils. Very little research has been done to measure low tensile strengths of soils. Shintaro et. al (2002) had conducted some tests on Kaoline soil to find the tensile strength. But the data they had obtained have some variations.

In this paper, a new simple testing apparatus which can be easily used for both compacted and saturated soft to medium soils is described and the testing method is explained. Compacted soil specimen can be directly prepared within the mold of the apparatus itself. Also, by transferring the saturated soil specimen prepared in the special consolidation mold to the tensile mold of this apparatus, one can easily measure the tensile strength of saturated soft soils. Test results on compacted and saturated soils show that they are reproducible, and reliable. Effect of water content, dry density and the proportions and size of fine particles mixed in the soil are examined.

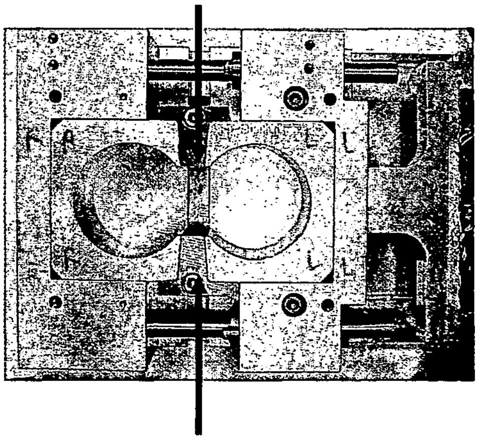
Tensile strength and unconfined compression test results are compared. The ratio of q_u to q_t was found to be around 12.5 for compacted Kanto loam. This value varies with water content at the wet and dry sides. In case of compacted mixtures (NSF clay-silt, NSF clay-sand and silt-sand), it is observed that with the increase in the amount of finer particles, there is increase in both q_u and q_t. But with the increase in the size of finer particles, both q_u and q_t decrease. Tensile strength measured for the one dimensionally pre-consolidated saturated NSF clay is compared with the unconfined compressive strength and it is observed that the ratio q_u/q_t is around 6.

Testing apparatus

Tensile test apparatus (Figure 1, Photo 1 and Photo 2) consists of a two halves box; a fixed box and movable one, resting on a horizontal platform. Inside this box, a newly developed tensile mold is placed. This tensile mold consists of two separate "C" structures whose inner shape is almost circular except at the portion where these two halves join. This mold holds the sample and its two halves are screwed to the apparatus box. One box of the apparatus is fixed to the horizontal platform while the other box can move freely on the horizontal platform. To reduce the friction between the movable box and platform, linear sliding roller is placed below the movable box and above the platform. Movable box is pulled away in horizontal direction until the soil specimen fails in tension as indicated by tensile crack appearing at the middle of the specimen where the two halves of the mold are attached. The load cell placed between the movable box and motor axis measures the tensile load. The tensile strength is obtained by dividing the tensile load by the area of the tensile crack perpendicular to horizontal pulling.

Two types of mold are used. In the first type (type-A, Photo 1, Figure 1), there is no bridging structure between the two halves. The total surface area of this mold is 38.51 cm^2 (total volume=192.53 cm^3) whereas in the second type (type-B, Photo 2), bridging structures having 1 cm thickness are placed in between the two halves. Total surface area of type-B mold is 41.51 cm^2 (total volume=207.53 cm^3). The minimum width for both types of mold is 3 cm and depth is 5 cm.

bridging structures between two halves



bridging structure between two halves

Photo 2. Apparatus with type-B tensile mold.

The apparatus box along with the mold and platform can be completely separated from the motor for preparing the specimen before the test. Compacted soil specimen is prepared within this mold by direct static compression whereas saturated specimen is prepared by direct transfer of consolidated specimen prepared in consolidation mold. Once the specimen is ready within the mold for the test, then it is connected to motor shaft. A load cell is attached between the motor shaft and the movable apparatus box. The rate of deformation is maintained at 0.35 mm/min.

Unconfined compression test is performed in a standard unconfined compression test unit and constant strain rate is maintained. The height of the specimen is 10 cm and diameter is 5 cm. Specimen is allowed to fail at a constant displacement rate of 0.1mm/min.

Materials, specimen preparation and installation

Materials

Index properties of materials used in this research are shown in Table 1. Only soil particles passing through 2 mm sieve are used for Kanto loam. To examine the effect of amount and size of soil particles, three types of mixtures were prepared; (a) clay and silt, (b) clay and sand and (c) silt and sand. Here, clay means NSF clay and silt means CFP-100 silt. This CFP-100 silt is prepared by crushing silica sand (Kawamura et. al, 2004). Sand used is Standard Toyoura sand. NSF clay, silt (CFP-100) and Toyoura sand are commercially available. Grain size distribution curve for each material is also shown in Figure 2. For saturated sample, NSF clay is used.

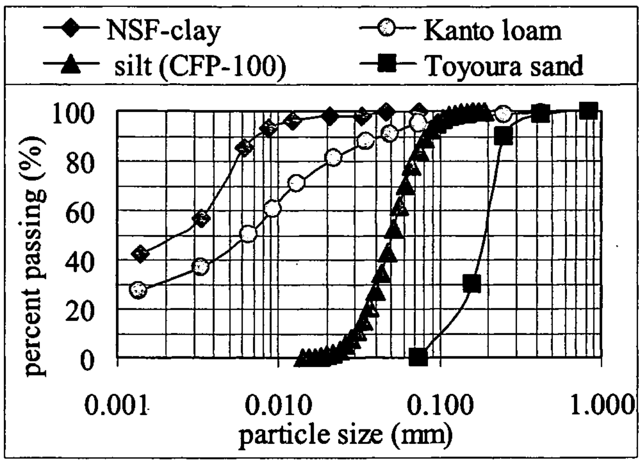


Figure 2. Grain size distribution curves.

Specimen preparation and testing procedure

Type-A and type-B molds are first assembled as shown in Photo 1 and Photo 2. Type-A is simpler and easier to handle. To prevent the free movement of movable part of the apparatus box before testing, the movable box is screwed to the apparatus horizontal plate. Also, to reduce the friction between the specimen and the inner wall

Table 1. Index properties

materials	ρ_s	clay	silt	sand	w_L	w_P	I_P	ρ_{dmax}	ρ_{dmin}
	(g/cm^3)	(%)	(%)	(%)	(%)	(%)	(%)	(g/cm^3)	(g/cm^3)
Kanto loam	2.646	44.5	50.5	5.0	143.5	74.6	68.9		
NSF-clay	2.776	74.0	26.0	0.0	55.1	30.6	24.5		
silt (CFP-100)	2.655	0.0	85.0	15.0				1.588	1.170
Toyoura sand	2.640	0.0	0.0	100.0				1.645	1.335

of the tensile mold, a thin film of grease is applied all over its inner surfaces.

Compacted specimen: Compacted specimens are prepared by thoroughly mixing the materials with prerequisite distilled water. Then they are kept in a plastic bag and sealed for a week so that water is uniformly distributed within the material. Specimens are then prepared by directly and statically compressing the prerequisite amount of water mixed material within the tensile mold of this new apparatus, using bellofram cylinder Water content maintained for Kanto loam is varied from 30 to 100 %. Compacted Kanto loam specimens are prepared at three dry densities (ρ_d); 0.66, 0.68 and 0.70 g/cm^3. In case of clay-silt mixture, they are mixed in the following proportions by weight; 25:75, 40:60, 50:50, 60:40, 75:25 and for clay-sand they are mixed in following proportions; 30:70, 35:65, 40:60, 45:55, 50:50, 55:45, 60:40, 65:35 and 70:30. Similarly, for silt–sand mixture, they are mixed in the following proportions; 00:100, 20:80, 40:60, 50:50, 60:40, 70:30, 80:20 and 100:00. Water content, (w) for all the mixtures is maintained around 10%. Dry densities for clay-silt, clay-sand and silt-sand mixtures are maintained at 1.5, 1.5 and 1.4 g/cm^3, respectively. Unconfined compression tests were also performed. For this, specimens are prepared in ordinary two parts splitting mold. One layer static compaction was followed in both the tests.

Pre-consolidated specimen: Saturated clay specimen is prepared in a separate consolidation mold by mixing NSF clay powder with two times of its liquid limit. De-airing of slurry is done before pre-consolidation. One dimensional consolidation was done. To reduce consolidation time, two-way drainage was allowed. Pre-consolidation stresses applied to the mixture varied from 100 to 300 kPa. Once the consolidation is over, pre-consolidated specimen is transferred to the tensile mold. Wire saw is used for cutting and trimming the upper surface of the specimen.

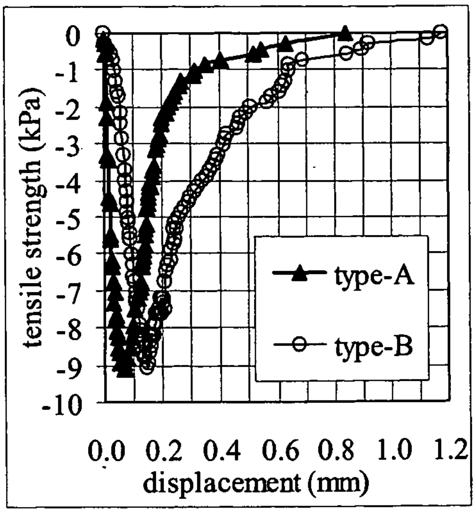


Figure 3. Results from type- A and type-B molds (clay-sand mixture: ρ_d=1.44 g/cm^3, w = 10%).

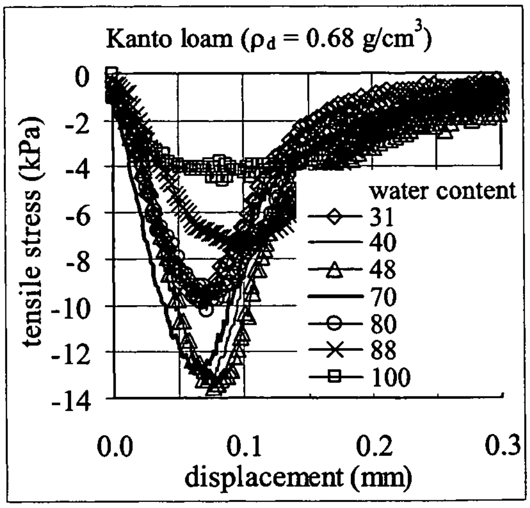


Figure 4. Relationship between tensile stress and displacement.

Results and Discussions

Test results of tensile tests carried out on type-A and type-B molds for clay-sand mixture (ρ_d=1.44 g/cm^3 and w=10%) are shown in Figure 3. Both types of molds gave almost same peak strength and showed the similar stress-displacement behavior. As the testing procedure with type-B is complex in comparison to type-A, it is therefore suggested to use type-A mold. From now onwards, test results obtained using type-A mold are only explained. Figure 4 shows the tensile stress-displacement curves for compacted Kanto loam, showing the peak tensile strength within 0.05 to 0.1 mm displacement range. Figure 5 shows the results of Kanto loam tests at different water content with repetition. Although, there are some differences in the maximum tensile strength for the repeated water content, it can be said that reproducible results can be obtained with this new apparatus.

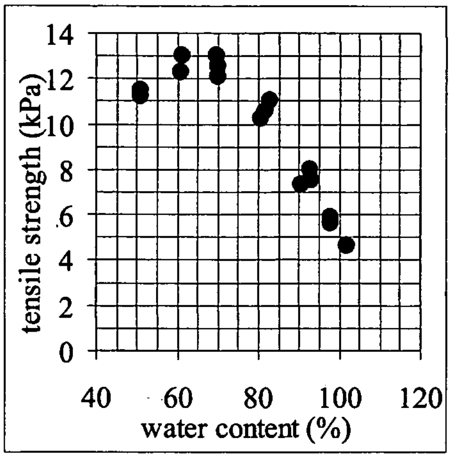


Figure 5. Repeatablity of tests (for Kanto loam).

Tensile cracks developed during the tensile tests are shown in Photo 3. Relationship between q_t, ρ_d and w for Kanto loam are shown in Figure 6. Three distinct curves are seen for three different dry densities. But all the curves show similar trend giving maximum tensile strength around 60% of water content. Tensile strength decreases along the both sides of this maximum value. Comparing the three curves, it can be said that with the increase in dry density, tensile strength also increases. But the difference in the tensile strength values with the change in dry density at two sides of maximum tensile strength is different, showing larger difference at the dry sides (lower than 60% water content) and smaller difference at wet sides (higher than 60% water content). At nearly saturated condition, tensile strength values are almost same. Therefore, it could be said that with the increase in dry density tensile strength also increases, but the ratio of increment depends upon the amount water content.

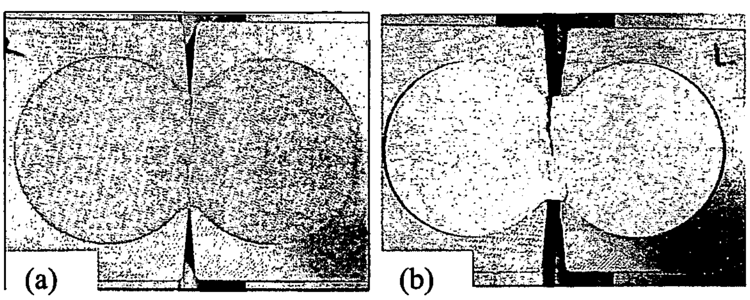


Photo 3. Tensile cracks; (a) compacted Kanto loam (w=40%, ρ_d=0.7 g/cm^3) and (b) saturated clay (pre-consolidated at 200 kPa).

Unconfined compression test results performed for compacted Kanto loam are shown in Figure 7. Here, the maximum q_u is seen around 50% of water content. The trend of curves is almost similar to that for tensile tests results shown in Figure 6.

Relationship between q_u and q_t is shown in Figure 8. Although there are some differences in the ratio with dry density, it can be said that q_u is 12.5 times larger than

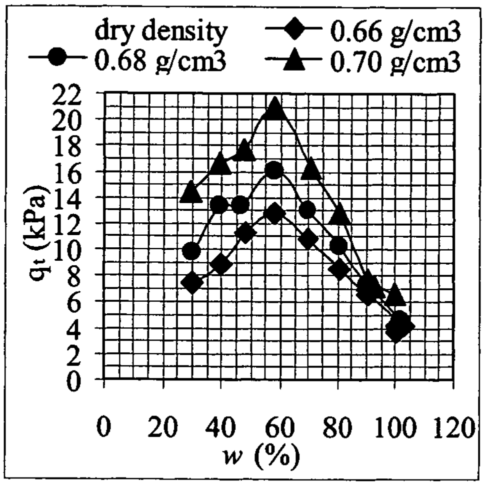


Figure 6. Relationship between q_t, w and ρ_d (for Kanto loam).

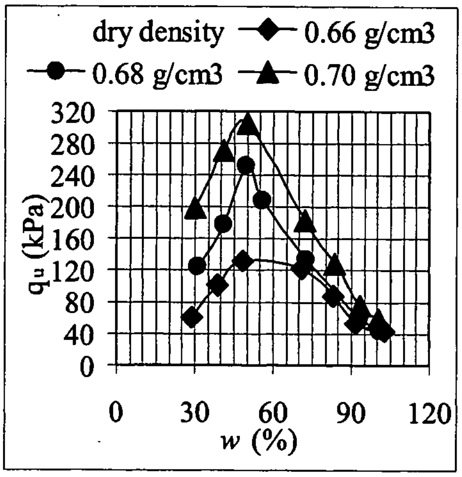


Figure 7. Relationship between q_u, w and ρ_d (for Kanto loam).

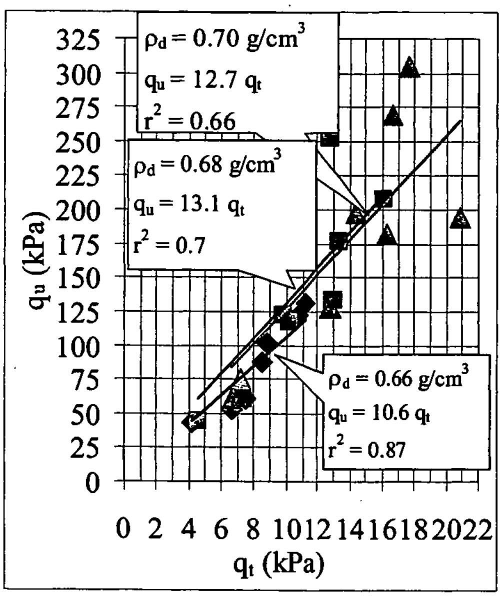


Figure 8. Relationship between q_u and q_t (for Kanto loam).

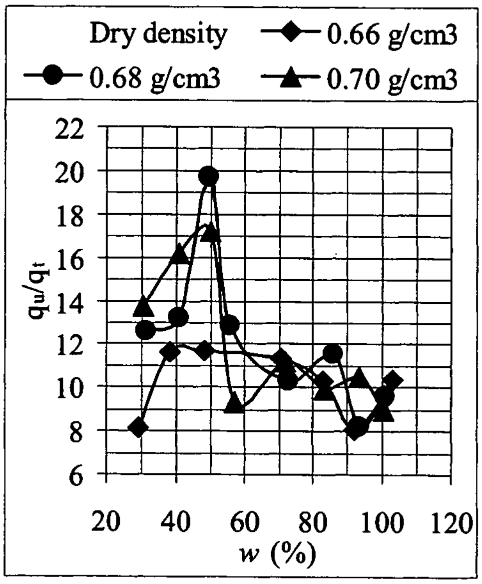


Figure 9. Relationship between q_u/q_t and w% (for Kanto loam).

q_t for Kanto loam. In Figure 9, it can be observed that the slope of the ratio (q_u/q_t) is different at dry and wet sides. With the increase in water content, this ratio increases at dry sides and decreases at wet sides. But the decreasing ratio of q_u/q_t at wet side is very less, showing the average value of 10. Hence, it is necessary to consider the water content if ensile strength is to be estimated from the unconfined compression strength.

The effects of amount and size of finer particles in the tensile strength are shown in Figures 10 and 11. Here, tensile test results of the mixtures; clay-silt, clay-sand and

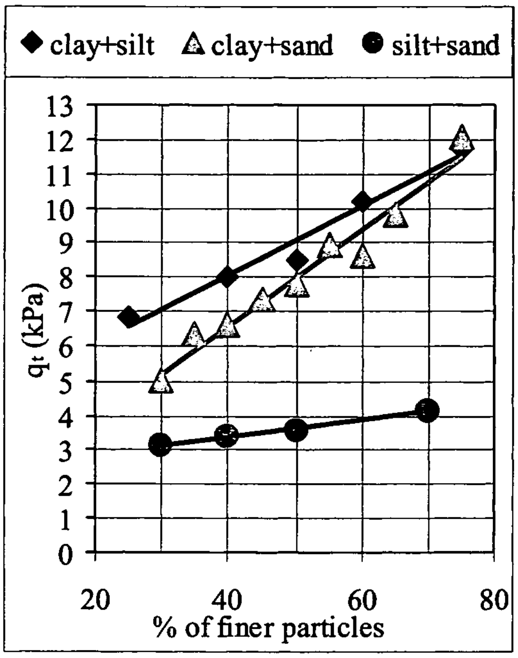


Figure 10. Tensile strength of compacted Mixtures.

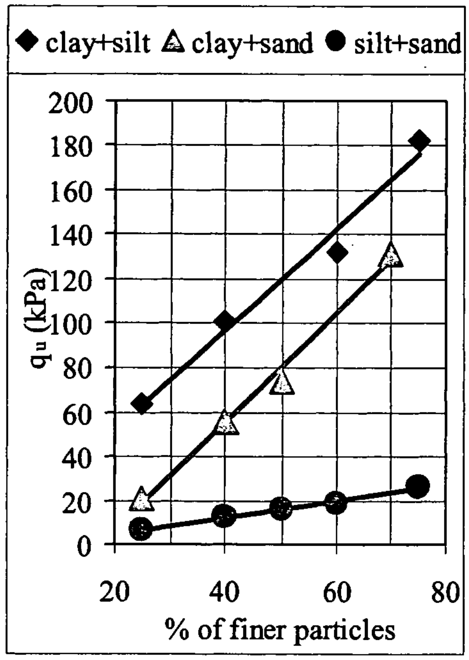


Figure 11. Unconfined compressive strength of compacted Mixtures.

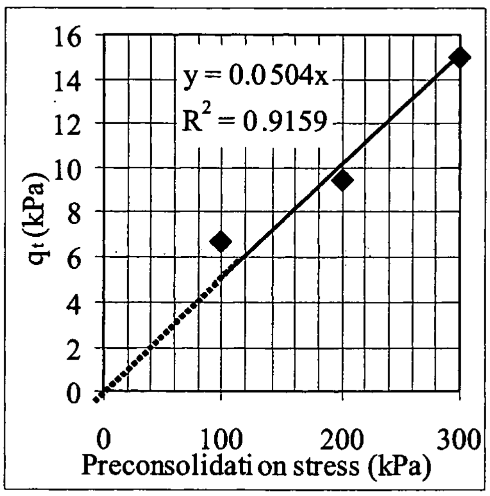


Figure 12. Pre-consolidation stress and q_t Relationship.

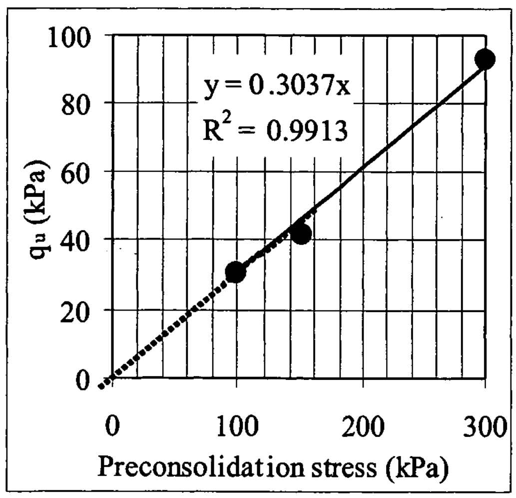


Figure 13. Pre-consolidation stress and q_u Relationship.

silt-sand are shown. All the curves show similar trend of increment in q_t and q_u with the increase in the amount of finer particles; clay in the clay-silt and clay-sand mixtures and silt in the silt-sand mixture. This implies that with the increase in the finer particles, both q_t and q_u increase.

Comparing the strength of mixtures compacted at ρ_d=1.5 g/cm^3 for clay-silt and clay-sand mixtures, it is seen that the strengths (q_t and q_u) of clay-silt mixture is higher than the strength of clay-sand mixture. Also, clay-silt mixture shows the highest strength and silt-sand mixture shows the lowest strength. Since the size of clay particles is smaller than the size of silt and sand particles, it can be said that the size of fine particles affects tensile strength; the larger the size of the fine particles, the smaller the tensile strength becomes. This might have occurred as there is a direct relationship between contact points of soil particles and strength of soils. Soils having more fine particles increase the contact surfaces between the particles which then increases the strength. According to Barzegar et al. (1995), different amount of finer particle shows different modes of particle arrangements within the soil matrix which influence the soil fabric and hence, the strength.

Relationships between the pre-consolidation stress and tensile strength and pre-consolidation stress and unconfined compression strength for saturated NSF clays are shown in Figures in 12 and 13, respectively. With the increase in consolidation stress, both q_t and q_u increase, showing their strength ratio (q_u/q_t) equal to 6.

Conclusions

From the tests conducted for statically compacted Kanto loam, clay-silt mixture, clay-sand mixture and silt-sand mixture; and saturated clay, following points can be concluded;

1. Newly developed tensile test apparatus can be used for measuring tensile strength of both compacted and pre-consolidated clayey soils. Both type-A and type-B tensile molds give similar results. Sample preparation in type-A mold is easy and simple.

2. Reproducibility of the test results is also verified.

Compacted Kanto loam

3. Maximum tensile strength and compressive strength are obtained around 50 to 60% of water content. With the increase in dry density, tensile strength and compressive strength also increase. The difference in the increment due to dry density is higher at dry side than that at wet side. At higher degree of saturation, differences become smaller.

4. The ratio of q_u and q_t is around 12.5, for Kanto loam. But there is a variation in this ratio with the water content. At dry side, it increases with the increase in water content, while at wet side, it remains almost constant.

Compacted mixtures of clay-silt, clay-sand and silt-sand

5. From test results of mixtures, it can be said that with the increase in the amount of finer particles (clay or silt), q_t and q_u both increase.

6. Also, smaller the size of finer particles (size of clay particle is smaller than size of silt and sand particles), higher the strengths of soil containing such fine particles.

Pre-consolidated Saturated clay

7. The ratio (q_u/q_t) obtained for pre-consolidated saturated clay specimen is around 6.

Acknowledgements

The authors would like to acknowledge Professor Satoshi Akagawa of Hokkaido University for his continuous inspiration in carrying out this research. In addition, the authors would like to extend their heartfelt thanks to Mr. Y. Kudoh of Hokkoido University for providing unconfined compression tests of pre-consolidated NSF clay. The authors would like to express their gratitude to Senior Researchers; Mr. N. Horii and Mr. S. Tamate and Researcher, Mr. T. Ariki for their valuable suggestions and discussions during the experiments.

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Newly developed tensile strength apparatus for soil and the factors affecting its measurement

Tensile strength, Laboratory test, Kanto Loam

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Ditto ditto Yasuo Toyosawa
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1. Introduction

Very few researches have been made to measure the tensile strength of soils having lower tensile values. Recently, Yao et al., 2002 and Nahlawi et al., 2004 have introduced an apparatus for the direct measurement of tensile strength which could be used to measure the tensile strength of soil having lower tensile strength. But the use of those apparatuses for the soil having higher degree of saturation is little difficult. Here, a newly developed tensile strength measuring apparatus which could measure the tensile strength of both compacted unsaturated (tamrakar et al., 2004) and saturated (tamrakar et al., 2004) soils more efficiently is used. In this paper, factors affecting the measurement of tensile strength using this newly developed apparatus are explained using compacted Kanto loam and the mixtures of NSF clay and Toyoura sand.

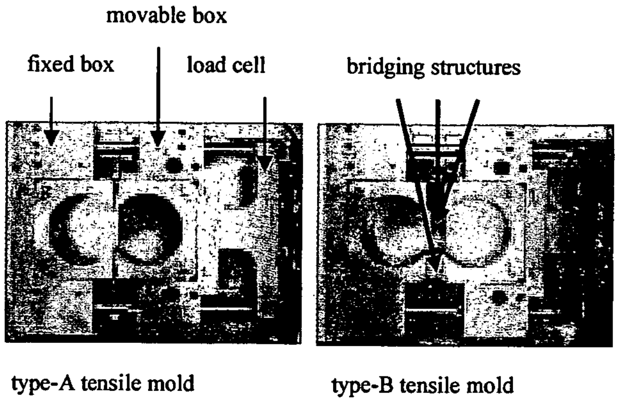

Photo 1 Tensile strength measuring apparatus

2. Testing Apparatus and Testing Method

Tensile test apparatus (Photo 1) consists of horizontal platform upon which apparatus box having two halves; fixed box and movable box, is placed. Inside this box, tensile mold is placed. This tensile mold consists of two separate "C" structures whose inner shape is almost circular except at the portion where these two halves join. To see the effect of stress concentration at the most constricted part where the molds join, two types of molds; type-A and type-B are used. Type-A (Photo 1) has no bridging structures whereas type-B consists of 1 cm thick bridging structure in between two halves. The minimum width for both types of mold is 3 cm and the depth is 5 cm. For specimen preparation refer to Tamrakar et al., 2004.

3 Test Conditions

To see the effect of test results using type-A and type-B tensile molds, mixture of clay-sand (dry density, ρ_d=1.44 g/cm^3, water content, w=10%, thickness, t=5 cm, static one-layer compaction (1-LC) and tensile pulling rate, T_{pr}=0.34 mm/min) is used. To see the reproducibility of test results, tests of Kanto loam (K-1) with type-A tensile mold are carried out with 1-LC, t=5 cm, ρ_d=0.68 g/cm^3 and T_{pr}=0.34 mm/min. To see the effect of tensile pulling rate, no. of compacted layer and thickness of the specimen within tensile mold, two types of clay-sand mixture prepared with the following proportions by weight; 25:75 (Mix-1) and 75:25 (Mix-2). The w and ρ_d for both types of mixtures are maintained at 10% and 1.5 g/cm^3, respectively. For these mixtures, T_{pr} is varied as 0.17, 0.34 and 0.88 mm/min with specimen t=5 cm and 1-LC. Kanto loam specimen (K-3) are used to see the effect of tensile pulling rate which varied from 0.09 to 1.75 mm/sec with t= 5 cm and 1-LC, w= 55% and ρ_d=0.63 g/cm^3. For the tests where the effect of number of compaction layers is studied, one-layer, two-layer and four-layer of static compaction are done without changing specimen thickness and dry density and maintaining T_{pr} at 0.34 mm/min. For the tests where the effect of specimen thickness is studied, 1-LC is done with the specimen thickness varying as 5 cm, 3.75 cm, 2.5 cm and 1.25 cm. Here also, T_{pr} is maintained at 0.34 mm/min.

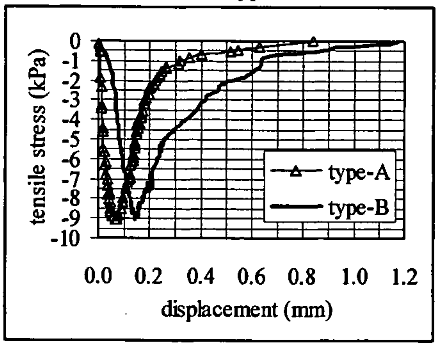

Fig. 1 Comparison of tensile mold results

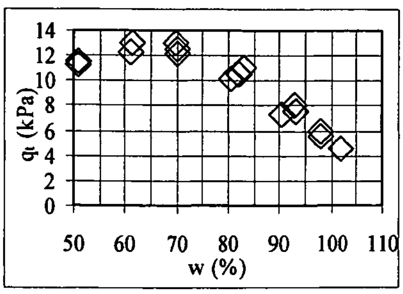

Fig. 2 Repeatability of the tests (K-1)

Newly developed tensile strength apparatus for soil and the factors affecting its measurement
Surendra B. TAMRAKAR, Yasuo TOYOSAWA, Kazuya ITOH (National Institute of Industrial Safety) and
Toshiyuki MITACHI (National Institute of Industrial Safety)

3. Test Results

The test results of tensile tests carried out on two types of molds for Mix-1 are shown in Fig. 1. Stress-displacement behavior and peak strength values are almost identical for both types of mold. As the testing procedure with type-B is a little complex in comparison to type-A, it is therefore suggested to use type-A mold for the tests. Fig. 2 shows the results of repeated tests on Kanto loam (K-1). Although, there are some differences in the tensile strength obtained for the repeated tests, it can be said that with this new apparatus repeatability of test results can be obtained. Tensile strengths are shown with positive values in this figure.

Fig. 3 shows the tensile strength measured for Kanto loam (K-3) at different tensile pulling rates. From the graph shown, it could be seen that at T_{pr} of 0.34 mm/min, measured tensile strength is the minimum. Along the both sides of this pulling rate, tensile strength is increased with the increase and decrease in pulling rates. Similar results are seen for the mixed samples (not shown here). Fig. 4 shows the effect of number of compaction layers (one-layer, two-layer and four-layer) made on the tensile strength. Although there is increase in tensile strength with the increase in number of compaction layers, the increment is not so much. That is to say that there is little effect of number of compaction layers on tensile strength.

The effect of thickness of the specimen (5, 3.75, 2.5 and 1.25 cm) within the tensile mold is shown in Fig. 5. Here, with the increase in the thickness, there is decrease in the tensile strength, 5 cm thickness which is the thickness of the tensile mold showing the minimum value. This might be due to the effect of momentum as the tensile apparatus is pulled from the mid-depth of the apparatus. It is always suggested to pull the apparatus from the middle for the specimen thickness.

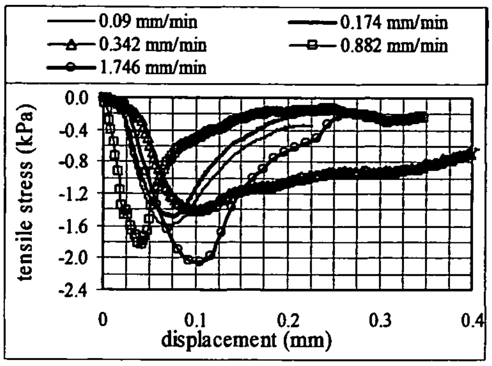

Fig. 3 Effect of pulling rate on tensile strength Kanto loam (K-3)

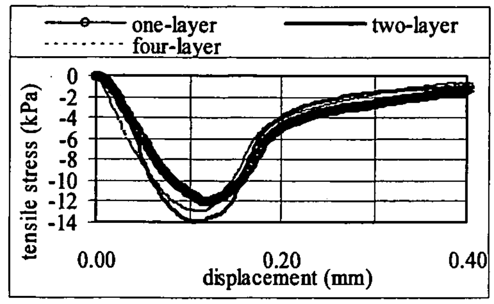

Fig. 4 Effect of no. of compaction layers (Mix-2 soil)

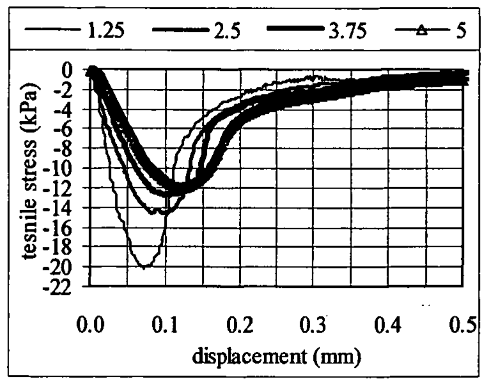

Fig. 5 Effect of thickness on tensile strength (Mix-2 soil)

4. Conclusions

From the tests conducted for statically compacted Kanto loam and the mixture of NSF-clay and sand, following points can be concluded;

1. Both type-A and type-B tensile molds give similar results. For type-A mold, specimen preparation is easy and testing method is simple. In addition, repeatability of the test results is also verified.
2. With the change in the tensile pulling rate, there is change in tensile strength. Tensile pulling rate of 0.34 mm/min gives the minimum tensile strength.
3. With the increase in the number of compaction layers, there is increase in tensile strength, one-layer compaction showing the minimum value.
4. Comparing the tensile strength of clay-sand mixture varying the thickness from 5, 3.75, 2.5 and 1.25 cm, it could be said the specimen with 5 cm thickness give the minimum value of tensile strength.

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Fig. 5 Effect of thickness on tensile strength

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Measurement of Tensile strength and the effect of finer particles

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1. Introduction

Recently, a new tensile strength measuring apparatus for measuring the tensile strength of soil has been introduced by Tamrakar et al. (2004). Accordingly the apparatus could be used for both saturated and unsaturated (compacted) soils. In addition, the apparatus is simple to use.

In this paper, tensile strength of saturated (NSF clay, DOTAN and the mixture of KIBUSHI clay and SEKIEI silt) and compacted (mixtures of Kaoline-Silt, Silt-Sand and Sand-Kaoline in different proportions) soils is measured and the effect of amount and size of the soil particles in the tensile strength is studied. Unconfined compression tests are also performed and they are compared with the tensile strength.

2. Testing Apparatus

Tensile test apparatus shown in Photo 1 consists of a horizontal platform upon which a newly developed tensile mold is placed. This tensile mold consists of two separate "C" shaped forms which are almost circular in shape except at the middle portion where these two halves are joined. Minimum width at this minimum portion is 3 cm. Depth of the mold is 5 cm. The attachment of one of the box to the horizontal platform is fixed while another box can freely move on to the platform in the horizontal direction. To reduce the friction between the movable body and the platform which was about 70 gram-force, linear sliding roller is placed in between. Movable box is pulled out by the motor attached with the horizontal platform.

3. Specimen Preparation and Installation Process

Saturated specimens of NSF clay (Kaoline), DOTAN and mixtures of KIBUSHI Clay and SEKIEI Silt are prepared by mixing them with distilled water at 2.5 times of their liquid limit and consolidated in a special mold (tamrakar et al., 2004) under different consolidation pressures; 50 kPa for Dotan and 100, 200 and 300 kPa for Kaoline and the mixtures of KIBUSHI Clay and SEKIEI Silt. Then they are directly pushed into the tensile mold with sufficient attention. Wire saw is used for cutting and trimming of the specimen.

Compacted specimens of Kaoline-Silt, Silt-Sand and Kaoline-Sand are prepared by thorough mixing, maintaining the water content around 10%. Then they are kept in the air tight plastic bags for several days so that homogeneity in water distribution could be obtained. Static compaction is done by putting the predetermined amount of mixed materials (dry density is fixed) into the tensile mold. Dry density maintained for the mixtures of Kaoline-Silt, Silt-Sand and Kaoline-Sand are 1.5, 1.4 and 1.5 g/cm^3 respectively. Water content for all the compacted specimens are maintained at 10%

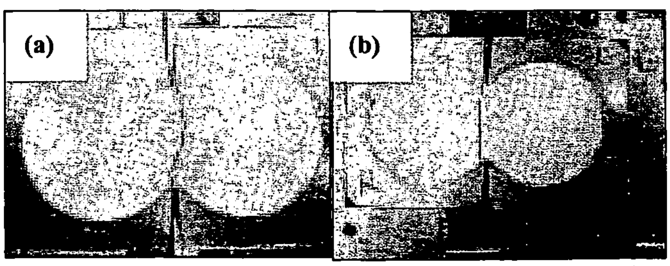

Photo 1 (a) Compacted soil and (b) Saturated NSF-Clay

Before putting the specimens into the tensile mold in both the compacted and saturated tests, a thin film of grease is applied on the inner surfaces of tensile mold and the inner bottom surface of the body in order to minimize the friction between the inner surfaces of mold and the specimen. After that the two halves of the tensile mold are screwed to the body. The movable

Tensile strength, Unconfined compressive strength, NSF Clay, Compacted soil

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body is fixed by screwing it to the horizontal platform before the sample preparation. Once the specimen preparation is finished, then load cell is attached at the movable body towards the pulling direction. Finally, movable body is freed and pulling is done by rotating the motor at the constant speed of 0.35mm/min. Unconfined compression tests are also performed for both saturated and compacted specimens.

4. Test Results and Discussion

Tensile cracks developed during the tests of compacted and saturated specimens are shown in Photo 1. Figure 1 shows the tensile stress vs. displacement curve obtained for saturated DOTAN clay consolidated at 50.2 kPa. From the graph, it is obvious that a clear stress-displacement curve could be obtained using this new tensile measuring apparatus.

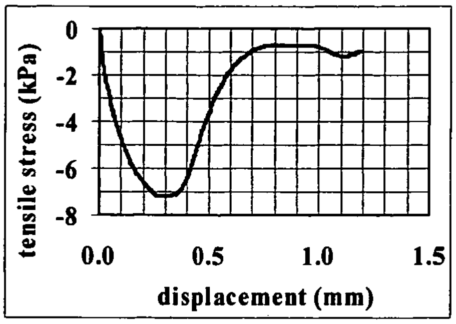

Fig. 1 Tensile stress~displacement curve

Table 1 shows the tensile strength (q_t) and compressive strength (q_u) obtained for saturated NSF-clay and the mixture of KIBUSHI Clay and SEKIEI Silt. As shown in the table, the ratio of q_u/q_t of NSG clay is around 3 where as that for the mixture is around 4.

Table 1 q_u and q_t of Saturated soils

Consolidation (kPa)	q_u (kPa)	q_t (kPa)	q_u/q_t
NSF-clay			
100	29.9	8.7	3.4
200	52.8	21.3	2.5
300	73.1	26.0	2.8
KIBUSHI Clay : SEKIEI Silt			
100	43.1	11.4	3.8
200	122.9	29.3	4.2
300	135.5	33.8	4.0

Tables 2, 3 and 4 show the q_t and q_u measured for Kaoline-Silt, Silt-Sand and Kaoline-Sand mixtures. In each table, it could be observed that there is increase in strength with the increase in the amount of finer particles (Kaoline in case of Kaline-Silt and Kaoline-Sand and Silt in case of Silt-Sand mixture). Among these three types of mixtures, Kaoline-Silt mixture which has the highest amount of finer particles, shows the highest values of strength than those by other two mixtures. Silt-Sand mixture shows the lowest value. Comparing the strength values and the ratio of strengths (q_u/q_t) of Kaoline-Silt and Kaoline-Sand (Tables 2 and 4), it could be seen that at the same % of Kaoline, the strength of Kaoline-Silt mixture is higher than that for Kaoline-Sand mixture. This means that the soil containing the smaller size of the finer particles gives shows the higher value of strength.

Table 2 Kaoline-Silt (CFP) mixture

% of Kaoline	q_u (kPa)	q_t (kPa)	q_u/q_t
25	63.6	6.8	9.3
40	97.4	8.2	11.8
50	119.9	9.2	13.0
60	142.4	10.1	14.0
75	176.2	11.6	15.2

Table 3 Silt (CFP)-Sand mixture

Silt(%)	q_u (kPa)	q_t (kPa)	q_u/q_t
25	6.6	3.0	2.2
30	8.4	3.2	2.7
40	12.1	3.4	3.6
50	15.8	3.7	4.3
60	19.5	3.9	5.0
70	23.2	4.2	5.6
75	25.0	4.3	5.8

5. Conclusions

1. Measurement of tensile strength for both saturated and compacted soils are possible by this new tensile strength measuring apparatus.

2. From the test results of Kaoline-Silt, Silt-Sand and Kaoline-Sand mixtures, it could be said that with the increase in the amount of finer particles, the ratio of q_u/q_t increases. But with the increase in the size of finer particles there is decrease in the strength ratio.

3. The ratio of q_u/q_t for saturated NSF clay and the mixture of KIBUSHI Clay and SEKIEI Silt are around 3 and 4 respectively. Tensile strength of saturated DOTAN (consolidated at 50.2 kPa) shows 7.2 kPa .

Table 4 Kaoline-Sand mixture

% of Kaoline	q_u (kPa)	q_t (kPa)	q_u/q_t
25	21.4	4.1	5.2
30	32.3	4.8	6.7
35	43.3	5.6	7.7
40	54.2	6.4	8.5
45	65.2	7.1	9.1
50	76.1	7.9	9.7
55	87.1	8.6	10.1
60	98.0	9.4	10.4
65	109.0	10.2	10.7
75	130.9	11.7	11.2

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Tamrakar, S.B., Toyosawa, T. and Itoh, K., 2004: Tensile strength of Compacted and Saturated soils using newly developed tensile strength apparatus, 59th JSCE National Conference, 3-279, pp. 557-558.

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Failure heights comparison during excavation using in-flight excavator

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ABSTRACT: Normal and combination of normal and trench excavations were carried out for the statically compacted model slopes of Narita sand, Kanto loam and mixture of NSF clay and Toyoura sand using in-flight excavator. Normal excavation corresponds to the excavation made behind and above the toe level. Combined excavation corresponds to the toe excavation (excavation below the toe level) made at particular distance from the slope toe where normal excavation was already performed. In both types, excavation is continued until slope failure occurred and height of slope just before failure is calculated. Decrease in the failure height with an increase in trench excavation depth was observed in all types of soil models. Maximum failure height was observed during normal excavation. Whereas the combined excavation made near the slope toe showed the minimum failure height. Failure height increases with the increase in the distance of toe excavation from the toe. This might be due to extra increase in overburden pressure behind the cut. Image analysis of the photographs taken during the tests showed small movement with small and partial failure for Narita sand and Kanto loam and large movement with block failure for mixed soil. Sharp increase in the displacement values just before the failure measured at the slope crest showed the possibility of predicting failure in advance.

1 INTRODUCTION

Most of the accidents take place during the excavation of lower parts of the slopes, especially the trenches (excavation below the toe level). Earlier Tamrakar et al. (2005) carried out the tests at centrifuge using in-flight excavator for volcanic sand with and without making trench excavations at the beginning and it was reported that the vertical height before the failure was larger for the excavation made without trench at the start of trench excavation than the excavation made with the trench. In their research, only one type of soil was used and only two tests (with the trench excavation at the beginning or at the end) were performed. In this research, trench excavations are made at different distances from the toe of the slope along with the normal excavation and the effect of trench excavation on the failure height just before the failure was studied. Comparison of failure heights observed for the normal and combined excavations is made. With this, a better and safer position of trench excavation could be made. In-flight excavator which could be moved vertically up and down and horizontally left and right within the centrifuge environment is used for the excavation. At first, normal excavation was carried out until failure occurred. Then the distance from the toe of the slope to the failure position was noted. Finally, combination of normal and trench excavations were carried out within the distance measured earlier. In this case, trench excavation was continued till the failure occurred. Finally, comparison of failure heights (height of the slope surface from the bottom line of excavation) for normal and combined excavations was made. Image analysis was also carried out by comparing the photographs taken at the start of excavation and just before the failure which shows the movement of soil mass behind the cut. Failure pattern of slope could be seen with this analysis. Deformation of top surface of the slope at each excavation was measured by setting up linear vertical differential transducers (LVDTs) on the slope top. Stepwise increment in the displacement with the progress of excavation was observed. LVDT set up closest to the crest showed the sharp increment just before the failure. This might be useful in predicting the failure in advance.

2 EXPERIMENTAL SETUP

2.1 *Preparation of model ground and model slope*

In this experiment, three types of soil; Narita sand, Kanto loam and the mixed soil were used. First two soils were collected from the Toke excavation site, Chiba prefecture, Japan. Third soil was prepared in the laboratory by mixing NSF clay and Toyoura sand in the ratio of 1:3 by weight. Physical properties, particle size distribution and direct shear test results of these soils are shown in Table 1.

Accordingly, Narita sand is classified as SF (Sand with fines ≤15%) and Kanto loam is classified as VH2-S (Volcanic sandy soil with liquid limit, $w_L \geq 80\%$) (JGS0051-2000). Liquid limit and plasticity index of Kanto loam used are 129.3% and 38.1%, respectively. Soil specimens were thoroughly mixed with pre-determined water content (w) and kept in plastic bag for several days. Model slope ground from these soils was prepared in a model box (0.45 m × 0.20 m × 0.272 m), by statically compacting them into number of layers using bellofragm cylinder. Model ground of Narita sand and mixed soil were prepared under 50 kPa where as model ground of Kanto loam was prepared under 25 kPa. Thickness of each layer is about 0.02 m and compaction time for each layer was about 5 minutes.

Once the compaction was completed, front and back panels of the model box were removed and model slope ground was then cut to required dimensions. Details of slope model are shown in Figure 1. Slope angle for each slope was fixed at 50 degree. This slope angle is lower than the one mentioned in the safety guideline of Labor Safety and Health Regulation. The lower and safer angle was selected so that longer slope length (i.e., distance of excavation from the toe of the slope) could be obtained which will facilitate to make trench excavations at different distances from the toe.

After making the model slope, side panels; with and without glass were attached to apparatus box in which model slope ground was made. In order to reduce the friction between the model ground and the model box panels, rubber membrane was placed in between. A thin film of silicon grease was applied between the membrane and the panels, which further reduces the friction. Lines (vertical and horizontal) were drawn on one side (glass) of the membrane so that it could be seen through the glass panel during the excavation. Later on, these lines were used to find the movement of the slope before and after the failure. Some parts of rubber membrane (from the toe to the distance at which the excavation was to be carried out) were cut into smaller pieces so that free movement of slope as well as clear excavation of each step could be commenced. The rubber membrane used has same size and shape as that of the model slope ground. Outline and final shape of the model ground are shown in Figure 1. Completed model slope along with model box was finally shifted to centrifuge platform. Direct contact type LVDT (D-1 to D-5) are placed on the top surface of the slope at 0.01, 0.04, 0.07, 0.105 and 0.142 m distances from the crest of the slope as shown in Figure 1. Once the set up of LVDT was finished, in-flight excavator was positioned in the centrifuge platform in such a way that its blade could move freely within the model box.

Table 1. Properties of soil specimens.

	Narita sand	Kanto loam	Mixed soil
γ_s (kN/m^3)	26.12	27.13	
$0.075 \times 10^{-3} \sim 2 \times 10^{-3}$ m (%)	77.50	11.50	
$0.005 \times 10^{-3} \sim 0.075 \times 10^{-3}$ m (%)	12.70	54.70	
$<0.005 \times 10^{-3}$ m (%)	9.80	33.80	
Avg. particle size, D_{50} ($\times 10^{-3}$ m)	0.1909	0.0119	
Uniformity coeff., U_c	40.70		
Coefficent of Curvature, C_c	13.9		
Cohesion, c (kPa)	9.78	6.12	16.80
Angle of internal friction ($\theta°$)	15.88	40.05	16.68

γ_s = unit weight of soil solids.

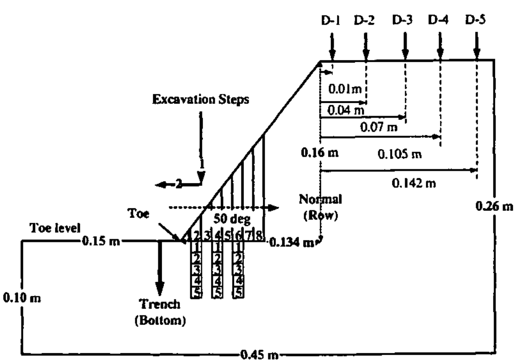

Figure 1. Outline of model slope showing the positions of LVDTs on the slope top.

2.2 *In-flight excavator*

In-flight excavator developed by Toyosawa et al. (1998) shown in Figure 2 was used in this research.

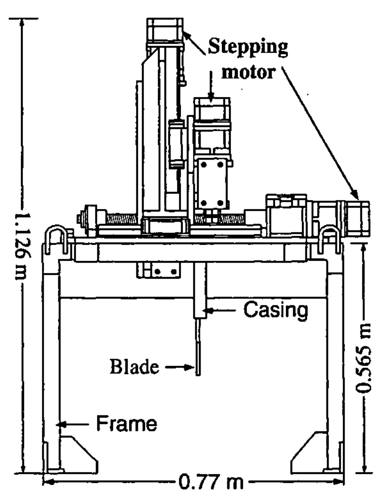

Figure 2. Outline of In-flight excavator.