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Mechanical and Environmental Properties of Plastics-included Landfills with Elastic Behavior (Resilient)

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INTRODUCTION··· *SLOPE STABILITY OF DEPOSITED SOLID WASTE*

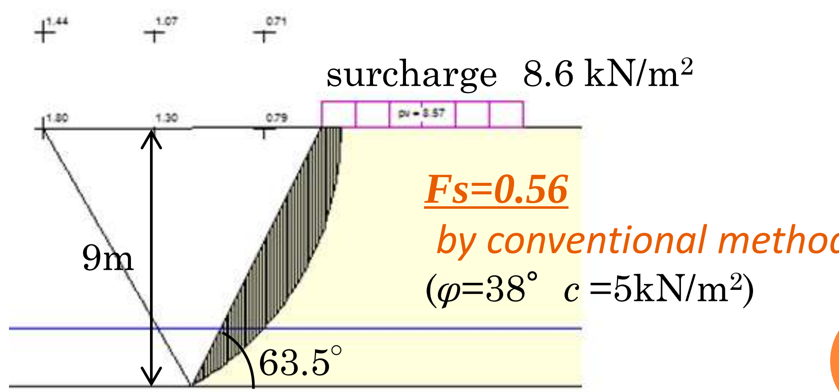
Upright Waste Wall (h=11.5m)

50m in height deposited (θ=40°)

High slope stability cannot be explained by the conventional method.

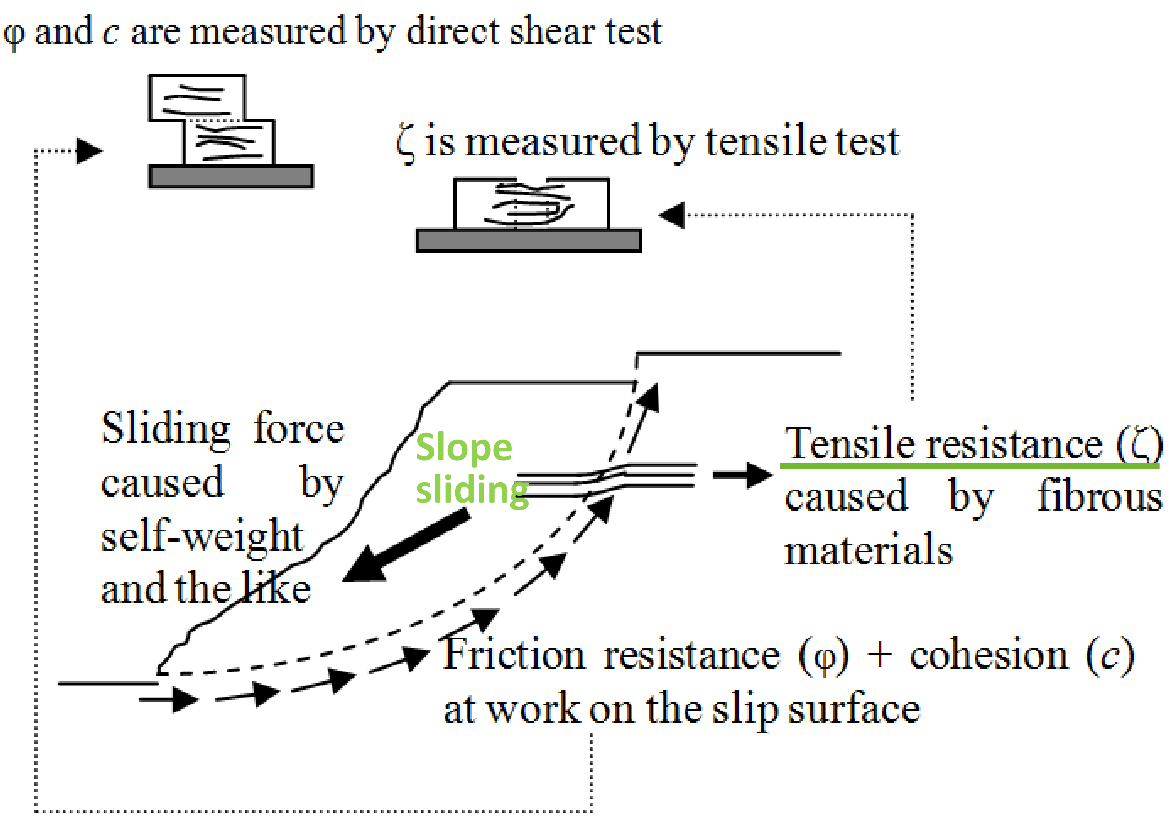
No collapse,
No displacement

Loading Test in Shanghai



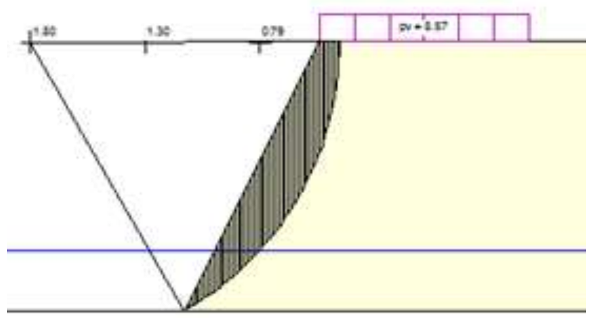
Explanation for slope stability of fibrous materials-containing deposit

by previous research (2010-2012)



Model of fibrous materials-containing deposit

in Shanghai



Fs=0.56 → 0.93

with tensile resistance

(φ=38° c =5kN/m^2 ζ=15°)

High slope stability can be explained by tensile resistance.

1. Aims

Waste ground including plastic inside and outside of Japan

Inert waste landfill site
(1,164 locations in Japan)

Controlled type landfill site
(753 locations in Japan)

Measured site of
illegal dumping

Temporal
deposit site of
disaster waste

Overseas
Landfill
(in Indonesia)

- Experts pointed out that
  "It cannot be used because the ground is too soft“
- No heavy structures have been ever built on landfills in Japan.

Our previous research has confirmed high shear strength.

Mechanical behavior of incineration ash ground is similar to soil ground.
Unclear properties remains
on waste ground including plastic.

- To clarify the mechanical and environmental properties of plastics-included landfills.
- To propose the investigation methods of these characteristics.
- To investigate possibility of using landfill sites.

2. Materials and Method

Study of slope stability（2010-2012）
Field data of 12 locations in 9 sites

Field tests for mechanical properties
Field data of 17 locations in 10 sites

Mechanical properties
・ strength parameters
・ settlement behavior

Study of new on-site tests
・Repose angle test
・impact acceleration test

laboratory experiment
・ shake table experiment
・ column experiment

Earthquake behavior
Drainage behavior

Full-scale experiment
・ Installing concrete foundation for a small wind turbine

Differential settlement
Environmental impact

"Proposed Manual for Utilization of Plastics-included Landfills"

3. Experiment Sites

Inert waste landfill


in Tohoku district


in Kanto district


in Chubu district


in Chugoku district

Controlled type landfill


in Tohoku district


in Kanto district


in Chubu district

Overseas landfill


in Turkey

4. Test Method

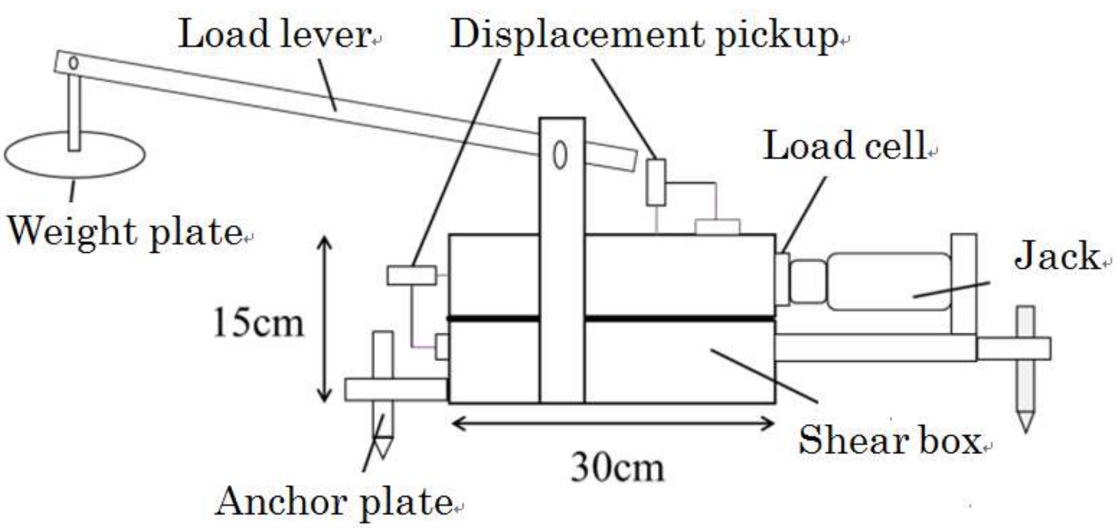
4.1 Plate load test

Plate Load Test *is a field test for determining the* ***Ultimate Bearing Capacity*** *of soil and the likely settlement under a given load.*

Given load;
0 - about 1000 kN/m^2

Plate we used ;
dia. 0.3m - 1.0m

4.2 Direct Shear Test



Direct shear test equipment

It can be installed on site without disturbing waste.

4.3 Impact Acceleration Test (CASPOL)

In the CASPOL test, a rammer is fallen from a height of 45 cm. **Impact acceleration** is measured by the built-in accelerometer of the rammer and the maximum value is detected and expressed as **impact value (*Ia*).**

Rammer (weight 4.5 kg
and diameter of 50 mm)

CASPOL, a simple bearing capacity measuring method **for earth grounds**, has been developed by the Kinki Construction Engineering Office, Ministry of Infrastructure, Land, Transportation and Tourism of Japan.

*We investigated the possibility of using CASPOL for approximate assessment of the bearing capacity of **landfills**.*

4.4 Repose angle test

Repose angle test *we designed is for investigating* ***stable slope angle*** *.*
And repose angle test is expected to enable estimation of the ***bearing capacity****.*

Solid waste spread out by backhoe

Measuring slope angle

Measuring height

Inert waste Landfill in Kanto

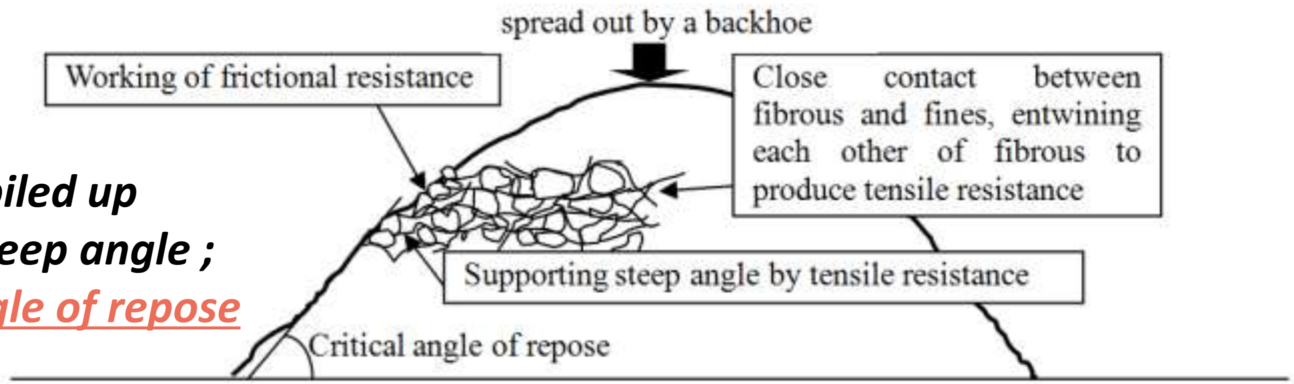
Inert waste Landfill in Chubu

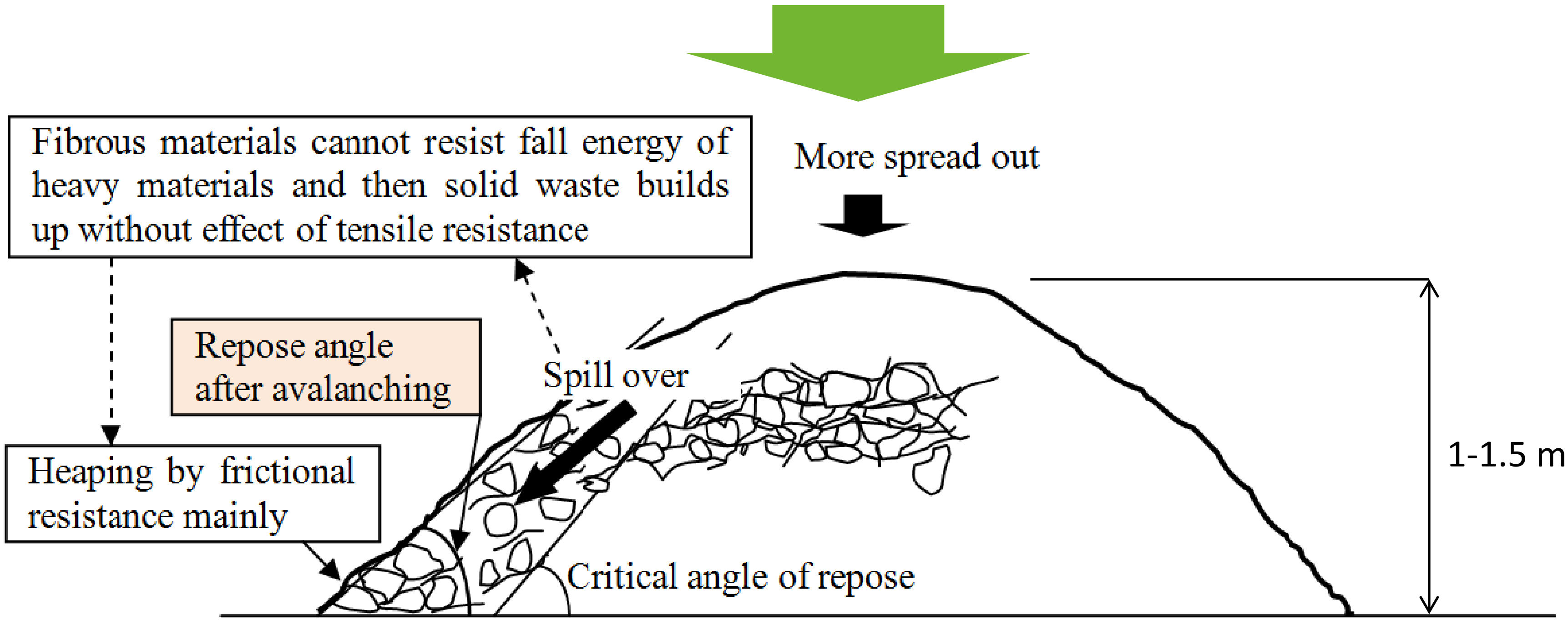
Controlled type landfill in Tohoku

Landfill in Turkey

Repose angle tests inside and outside of Japan

The heap piled up
with the steep angle ;
Critical angle of repose

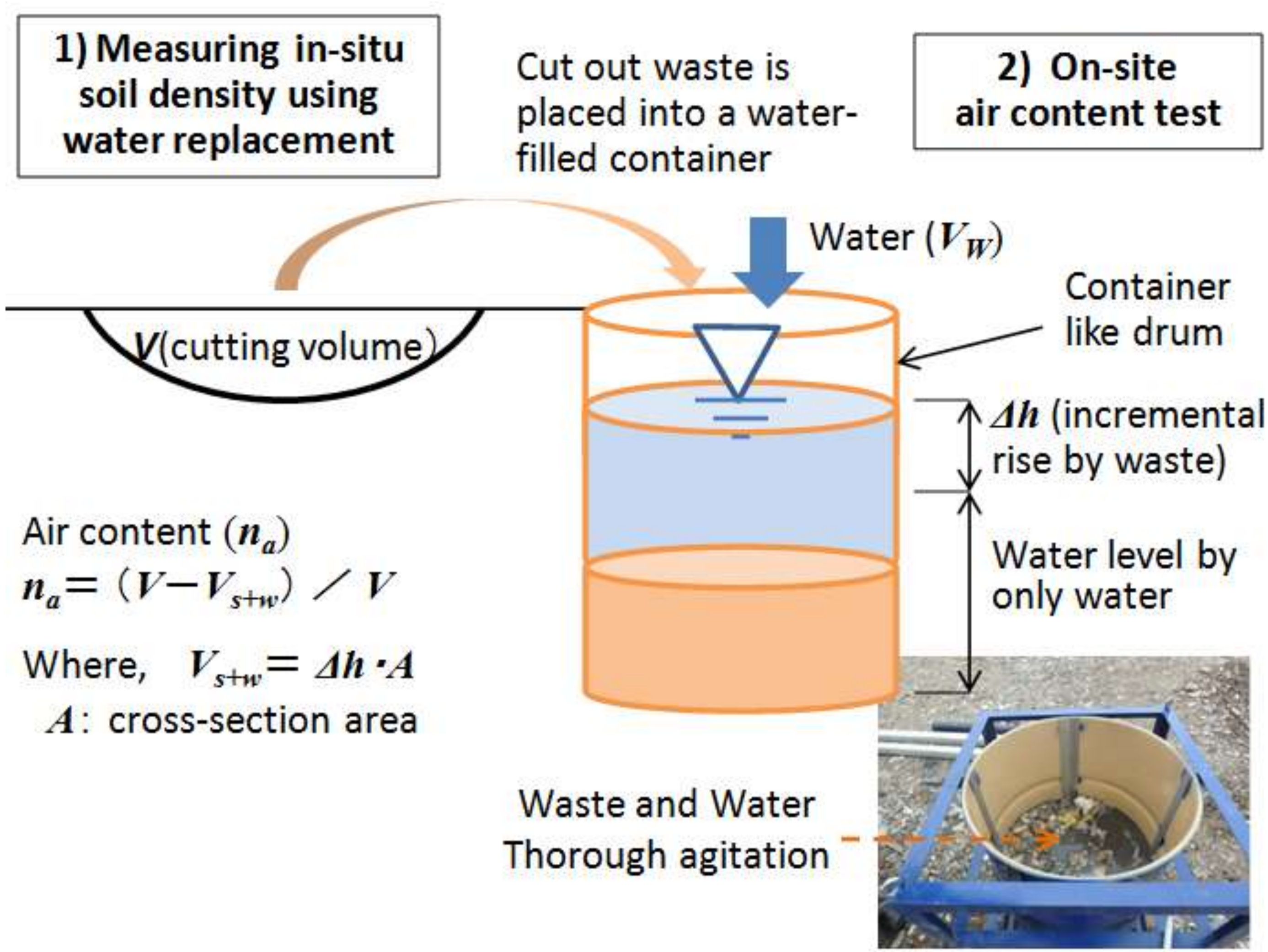




Slope angle become looser; Repose angle after avalanching

Illustrations of repose angle test

4.5 On-site air content test



***Air content** is expected to be related to **various strength parameters**.*

5. Results

5.1 Mechanical properties

Results of strength parameters obtained from 29 locations
(Next slide)

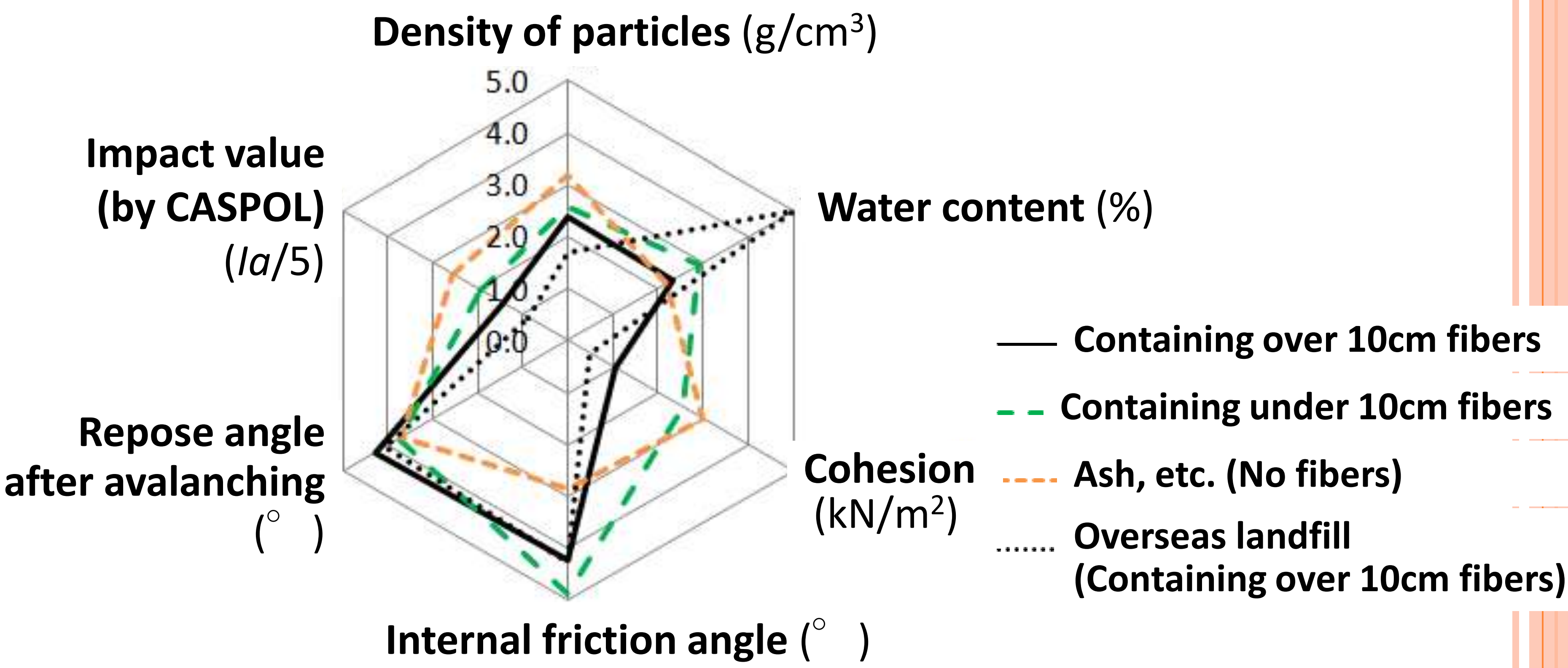
Relations between repose angle and slope stability

● *Slope failure or cracks occur when the slope angle exceeded the repose angle after avalanching, provided the original ground is flat.*
● *It can be demonstrated that repose angle after avalanching is a guide to assess slope stability of landfills.*

Fibers & size	Landfill type	Site	Composition (by weight)	Deposited time	Wet density	Water content	Air content	Ultimate bearing capacity	Coefficient of subgrade reaction	Cohesion	Internal friction angle	Critical angle of repose	Repose angle after avalanching	Conditions of slope		
				year	g/cm^3	%	%	kN/m^2	MN/m^3	kN/m^2	°	°	°	inclination °	condition	original ground
Over 10cm fibers	Inert waste landfill	Tohoku-A1	**plastic 54%, pottery,debris 45%	3.8	1.4	42	16	over 2000	111	22 *	41 *	51	41	27	stable	Inclined
		Kanto-A1	plastic 7%, soil 43%, pottery 44%	0.1	1.5	10	37	330	12	24 *	41 *	42	36	27	stable	Flat
			plastic 6%, soil 66%, pottery 18%	15.0	1.6	28	21	700	24	24	35	46	40	27	stable	Flat
		Chubu-A1	plastic 14%, soil 57%, debris 25%, rubber/leather 1%, metal 1%, others 2%	0.0	1.2	21	41	140	5	---	---	51	40	27	stable	Flat
				0.9	1.4	23	29	320	8	2	59	49	44	27	stable	Flat
				1.8	1.4	29	22	---	---	8	36	46	40	27	stable	Flat
				8.0	1.6	19	14	over 480	8	18	36	56	44	27	stable	Flat
			plastic 17%, soil 43%, debris 28%	15.0	1.5	23	17	over 640	12	5	38	51	43	27	stable	Flat
		Chugoku-A	plastic 6%, soil 59%, pottery 30%	0.3	1.1	25	39	340	8	11	27	46	38	27	stable	Inclined
	Illegal dumping	Kanto-C1	plastic 16%,soil/pottery 74%, metal 4%	10.0	1.2	31	---	---	---	3	46	60	50	90	surface collapse	Flat
		Chubu-C1 GL.2m	plastc 6%, debris 50%, soil 35%	1.5	1.2	21	---	---	---	4	51	53	45	60	cracks	Flat
		Chubu-C1 GL.7m	more plastics than above	1.5	0.9	13	---	---	---	3 *	51 *	58	52			
		Chubu-C2	**plastic 50%, debris 13%	13.0	0.7	17	---	---	---	3 *	47 *	55	45	25	stable	Flat
		Chubu-C3	mainly debris（few plastics）	0.5	---	---	---	---	---	---	---	42	36	36	stable	Flat
	Overseas landfill	Shanghai GL-1m	plastic 22%, soil/pottery 29%	7.0	1.1	39	---	---	---	6	33	---	---	63	stable	Flat
		Shanghai GL-3m	plastic 9%, soil/pottery 52%	7.0	1.2	45	---	---	---	4	43	---	---		stable	Flat
		Jakarta	kitchen waste, plastic-bag etc.	0.2	---	72	---	---	---	---	---	55	36	40	surface collapse	Flat
		Turkey	**kitchen waste 49%, packaging 24%	0.6	1.0	45	28	---	---	4 *	52 *	47	36	25	stable	Flat
Under 10cm	Controlled type landfill	Kanto-B1	plastic 8%, soil 73%, debris 10%	0.1	1.2	31	49	1600	51	40	50	42	40	---	stable	Flat
		Chubu-B	plastic 13%, soil 78%, pottery 5%	0.1	1.1	26	21	300	9	---	---	38	34	27	stable	Flat
			plastic 1%, soil 65%, pottery 30%	0.1	1.5	19	17	---	---	---	---	38	36		stable	Flat
	Disaster waste	Tohoku-E	soil 80%, debris 14%, wood 6%	0.5	1.1	40	---	---	---	11	47	45	40	40	stable	Flat
Ash, burnt residue (non fibers)	Controlled type landfill	Tohoku-B	burnt residue	0.8	1.5	22	39	---	---	45	19	40	36	27	stable	Flat
			ash	0.8	1.2	32	38	565	179	---	---	38	36			
		Kanto-B2	soil/burnt-residue 85%, debris 12%	12.0	1.4	---	---	---	---	over70	---	---	---	30	stable	Flat
	Illegal dumping	Tohoku-C	debris etc. (mainly soil)	10.0	2.0	18	---	over 360	59	14	17	37	35	27	stable	Flat
		Kyushu-C halfway	debris etc. (mainly soil)	9.0	1.4	23	---	---	---	3	45	50	44	30	cracks	Inclined (30°)
		Kyushu-C hill-top	debris etc. (mainly soil)	12.0	1.7	---	---	---	---	18	33	---	---			
	Municipal waste	Kansai-D	ash etc. (mainly soil)	40.0	1.1	14	---	---	---	---	---	40	36	40	surface collapse	Inclined

note 1) * ; by in-situ earth pressure test.（others ; by in-situ direct shear test） note 2) ** ; by carry-in record. (others ; by composition investigation)

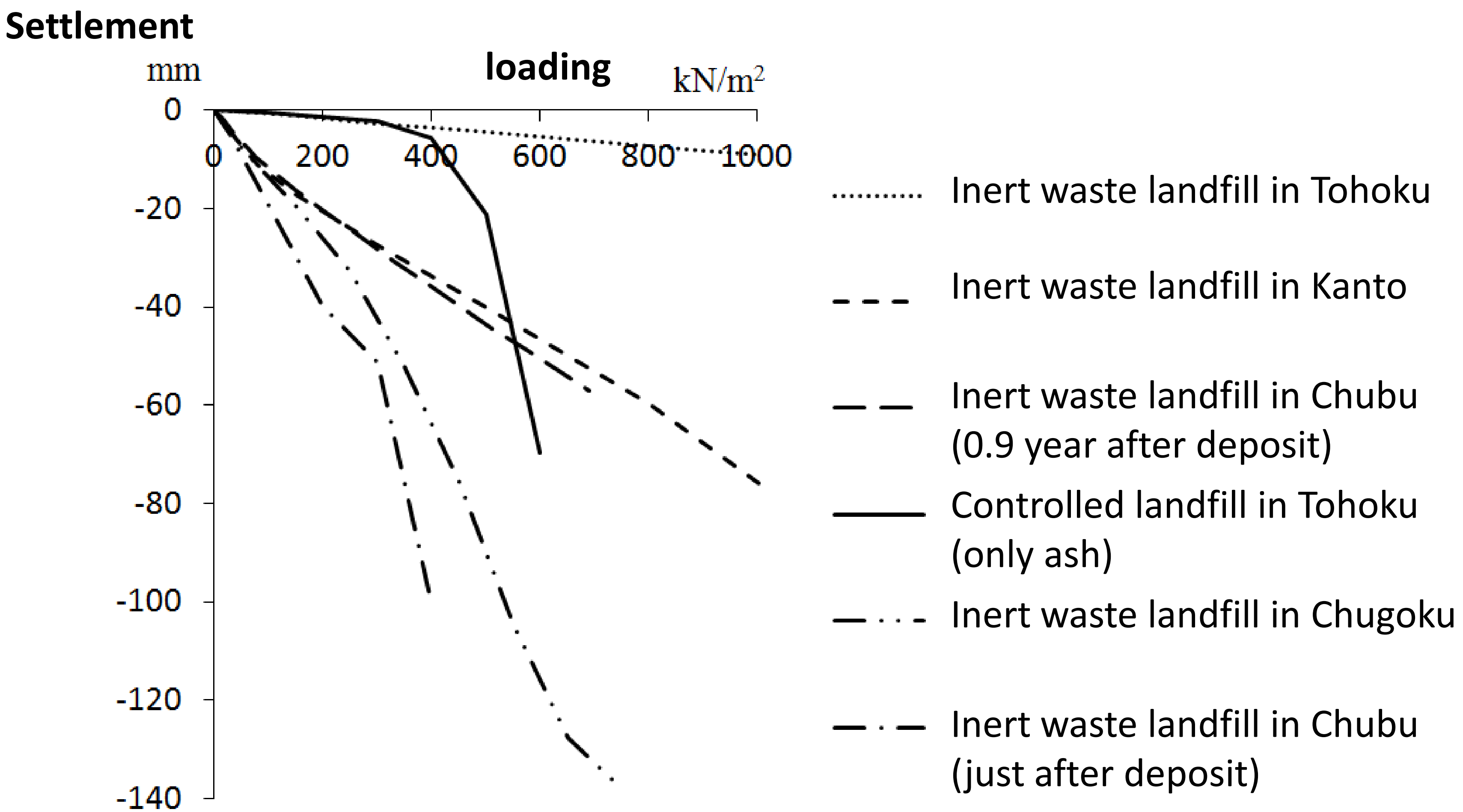
Mechanical characteristics by Landfill type



●*The mechanical characteristics of landfill depend on the composition and size of the waste. The mechanical characteristics vary considerably when the waste contains long fibrous materials (plastics, etc.).*

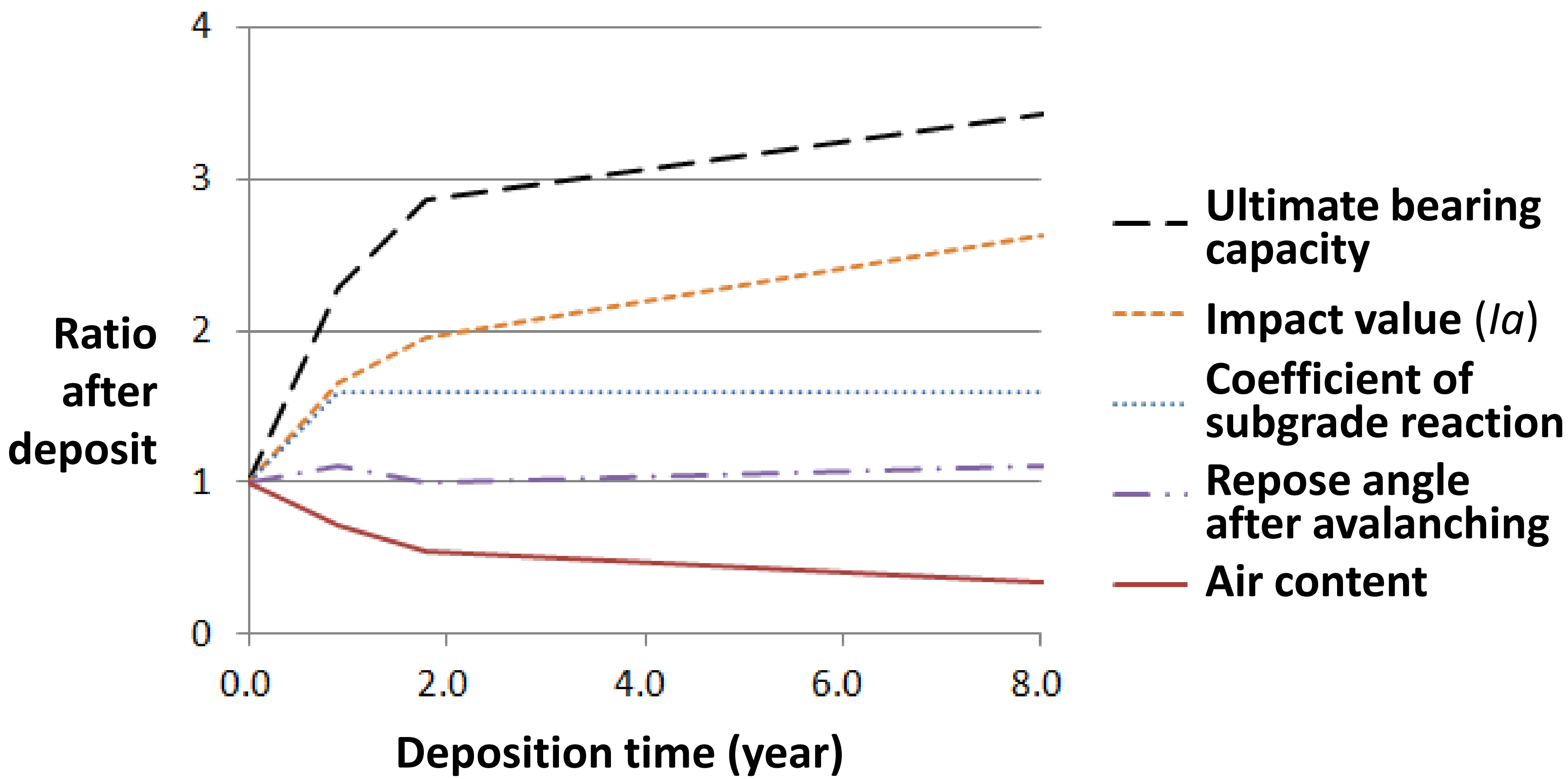
●*Grounds containing fibrous materials are easily deformable and flexible, but have high shear strength and bearing capacity.*

Plate load test results



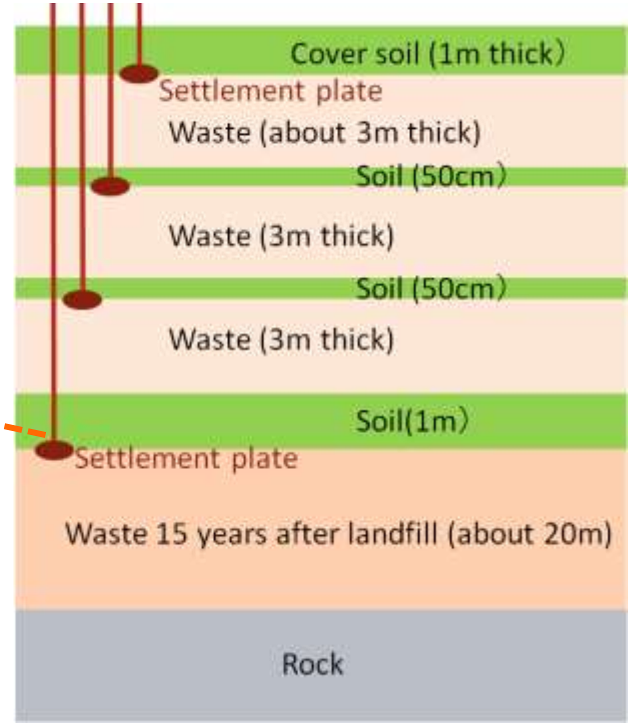
●*Except for the Tohoku B site which comprises only ash, increased loads do not cause significant settlement. This suggests that the actual ultimate bearing capacities may be yet larger.*

Strength parameters across the ages at Chubu inert waste landfill

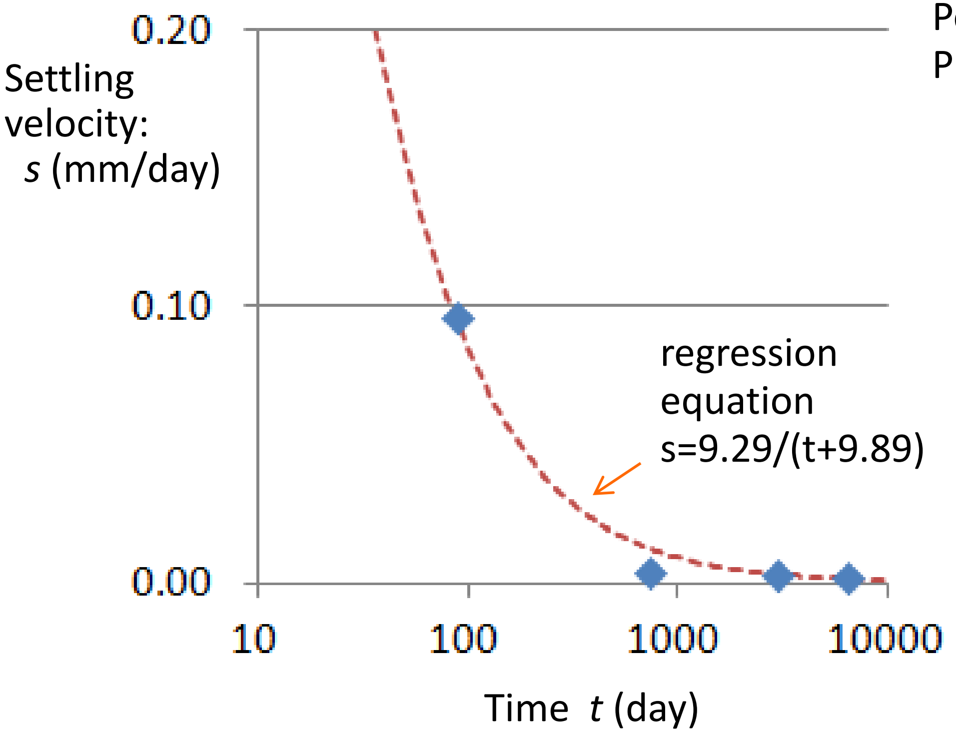


●*At a landfill which contains plastics of over 10 cm in length, air content inside the ground became lower over passage of time after the depositing, and the ultimate bearing capacity has increased remarkably.*
Air content is thus believed to be related to various strength parameters.

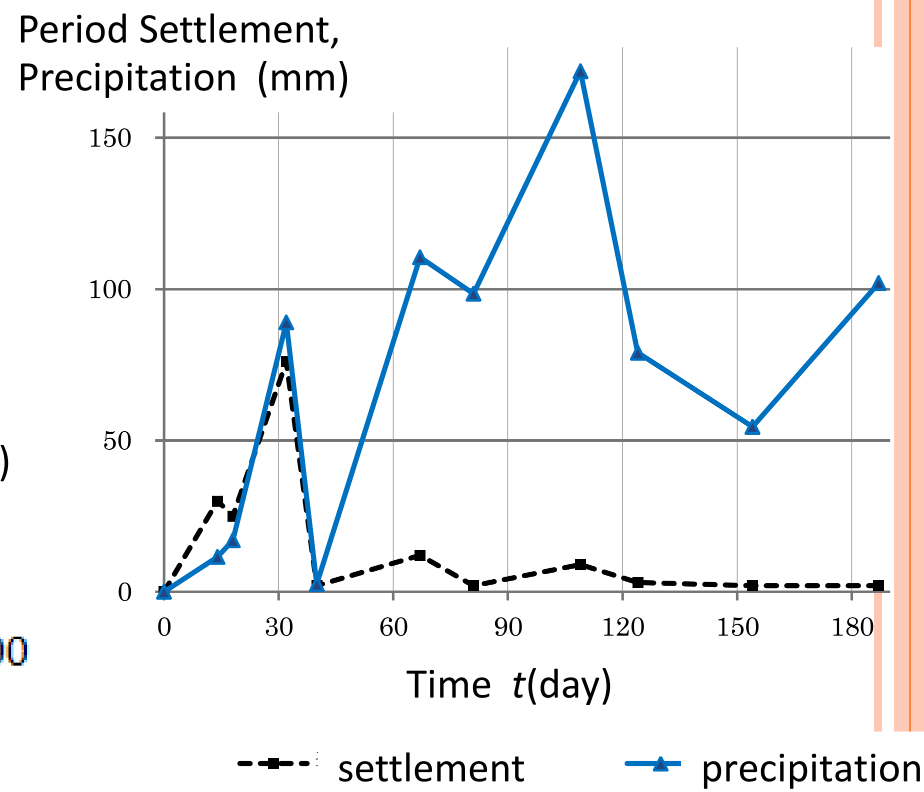
5.2 Settlement characteristics of solid waste grounds



*A settlement measurement was conducted at an **inert waste landfill site in Chubu district**.*
During April – June 2014, three new layers of solid waste were filled (total height :about 10 meters including two layers of intermediate cover soil) on top of solid waste of about 20 meters in height deposited over a period of 15 years over a rock bed.



Time – Settling velocity

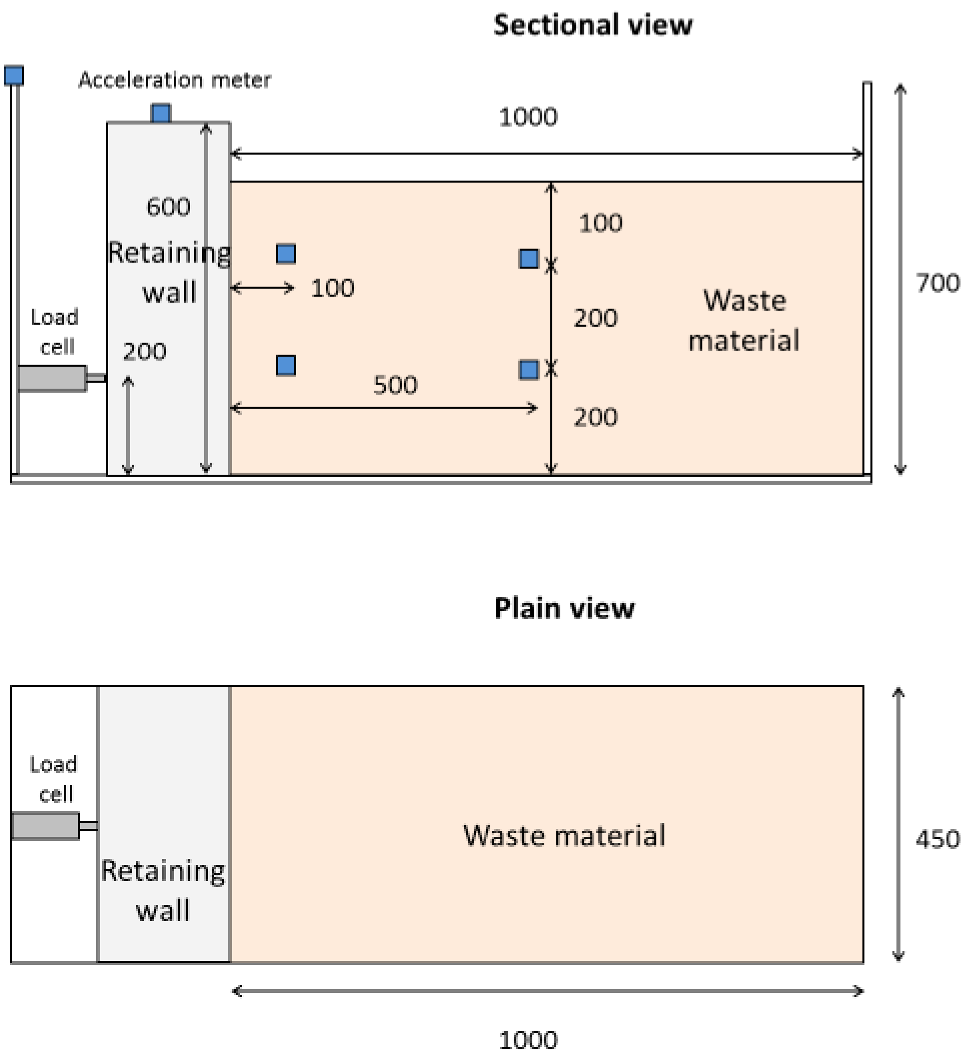


Time – Settlement, Precipitation

● *settlement progressed significantly during the initial period of about a month. Then the settlement progresses along hyperbolic curve. In the left figure, when the layer thickness is 10 m, settlement is 9 mm/year after ten years.*

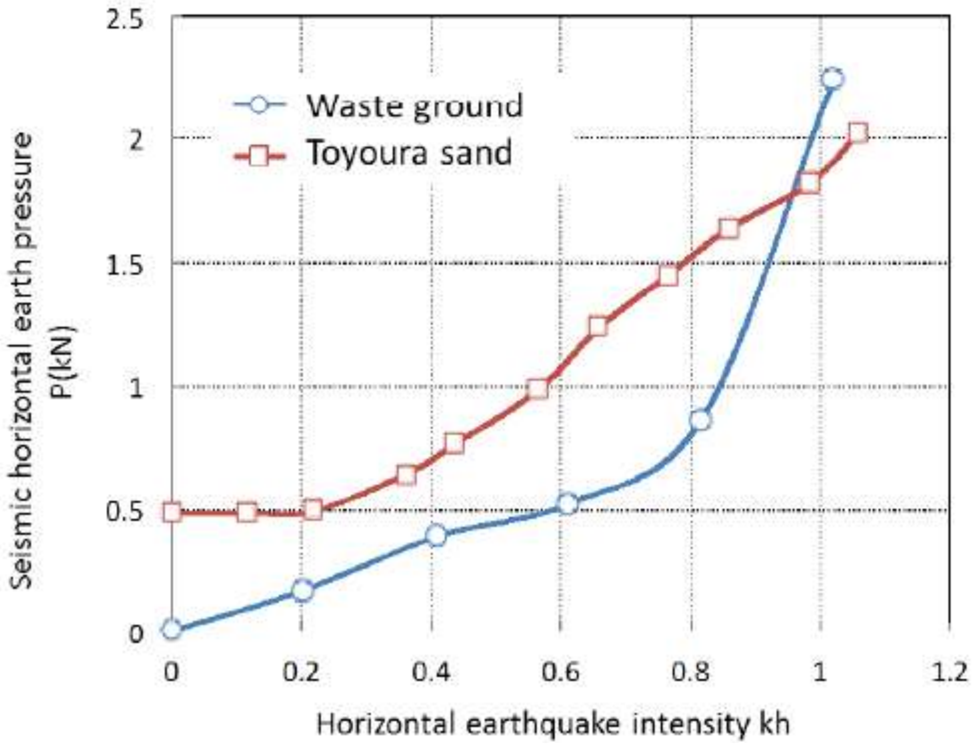
●*The initial settlement appears to be heavily influenced by the surcharge and rainfall.*

5.3 Seismic Earth Pressure of Waste Ground by Shaking Table Test



Outline of the experimental device

The situation of shaking table test



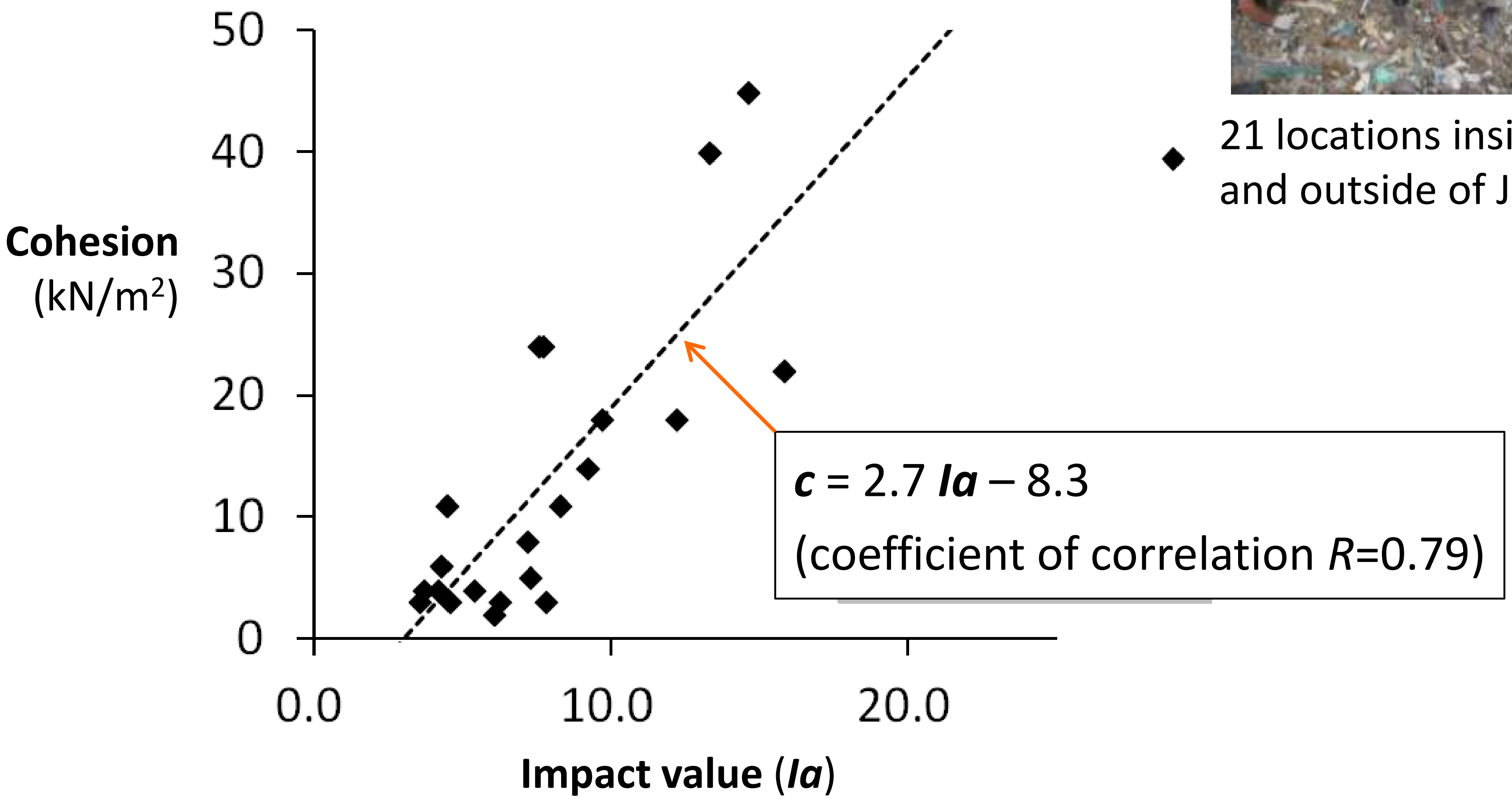
Result of the shaking table test on the waste ground with over 10cm fibers and comparison with the previous test on Toyoura standard sand

● *The seismic earth pressure of retaining wall on the waste ground is smaller than that of the sandy ground.*

● *It is considered that the waste ground with plastics has resilient property in comparison with sandy soil.*

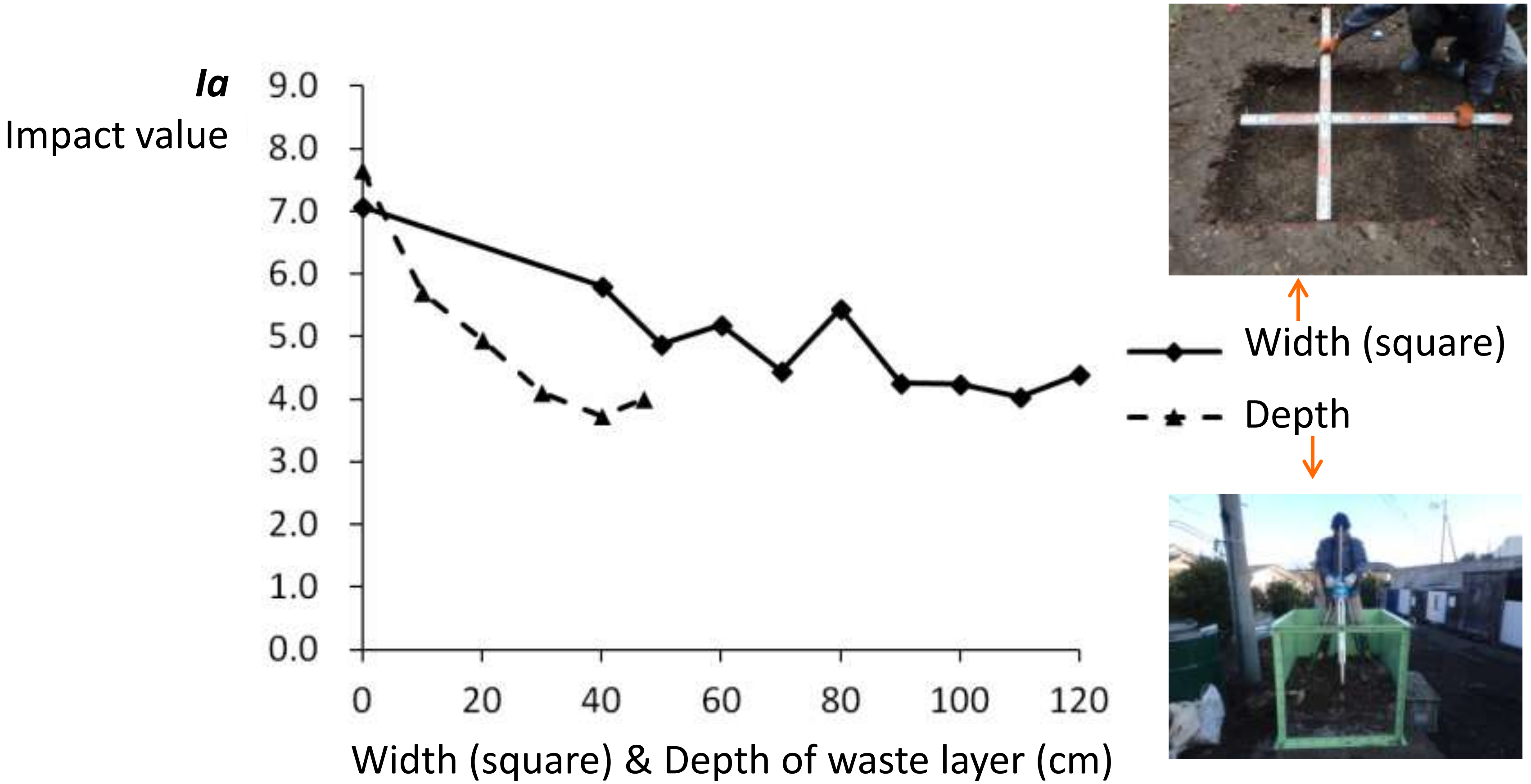
5.4 Applicability of the on-site test methods we devised

Result of Impact Acceleration Test



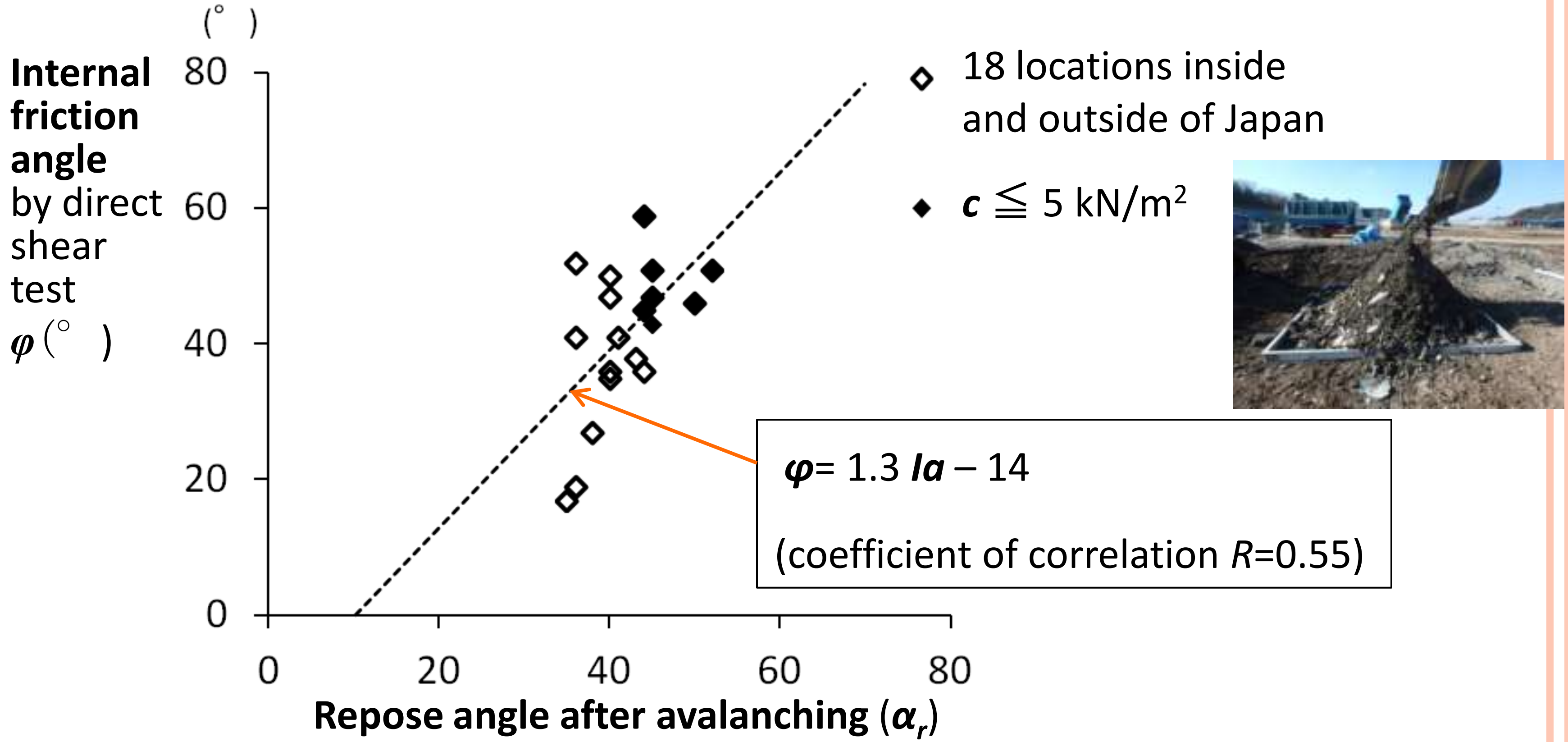
*Impact values (**Ia**) obtained by CASPOL are related to the cohesion (**c**) obtained by direct shear test.*

Influence extent confirmation test of Impact Acceleration Test



● *The extent of influence, namely the points where **Ia** reaches the lowest value, is in the range of 110 cm in width (13 - 24 cm in the case or earth grounds) and 40 cm in depth (earth ground 9 -22 cm). The influence is substantially more extensive in the width direction than in the case of earth grounds.*

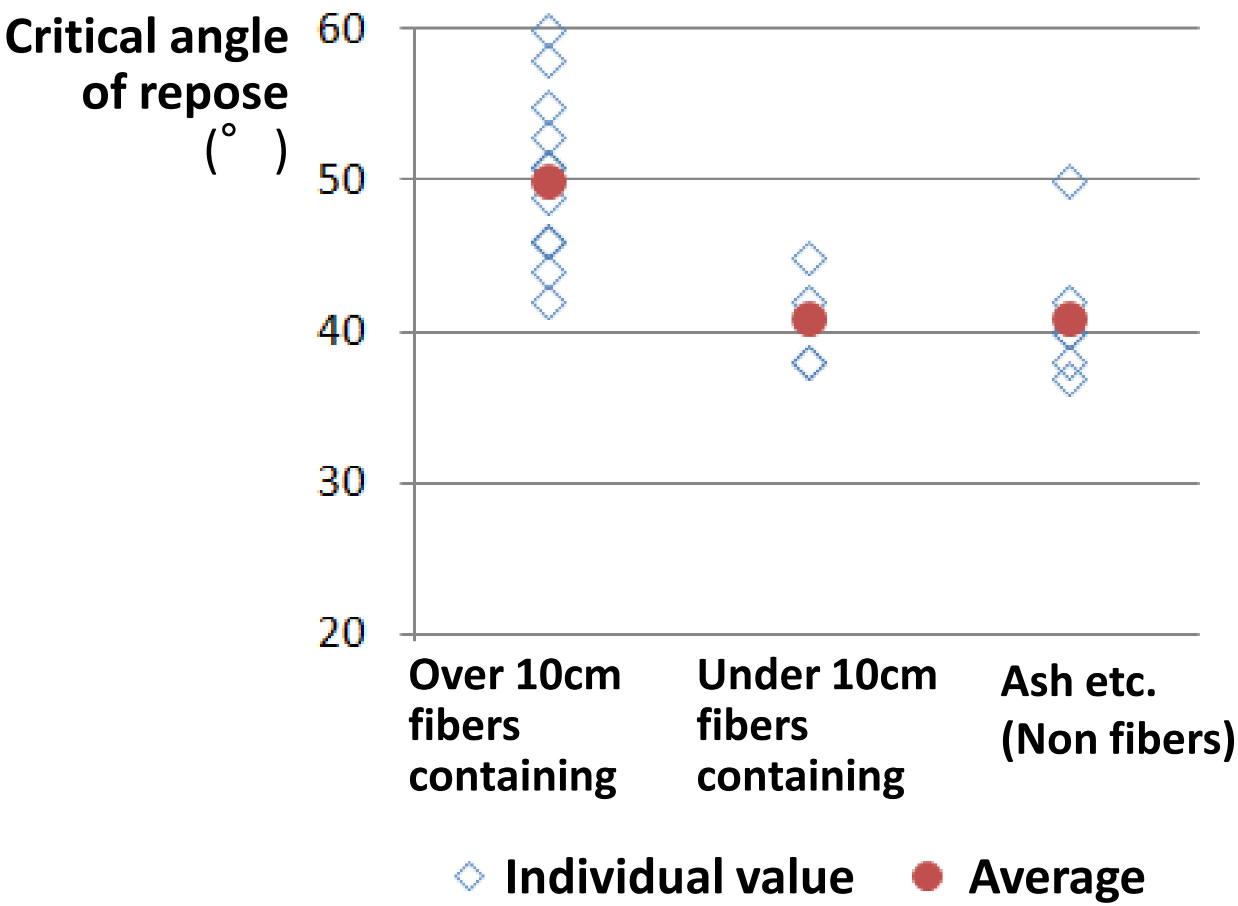
Result of Repose Angle Test



●*Repose angle after avalanching is related to the angle of internal friction from in-situ direct shear test.*

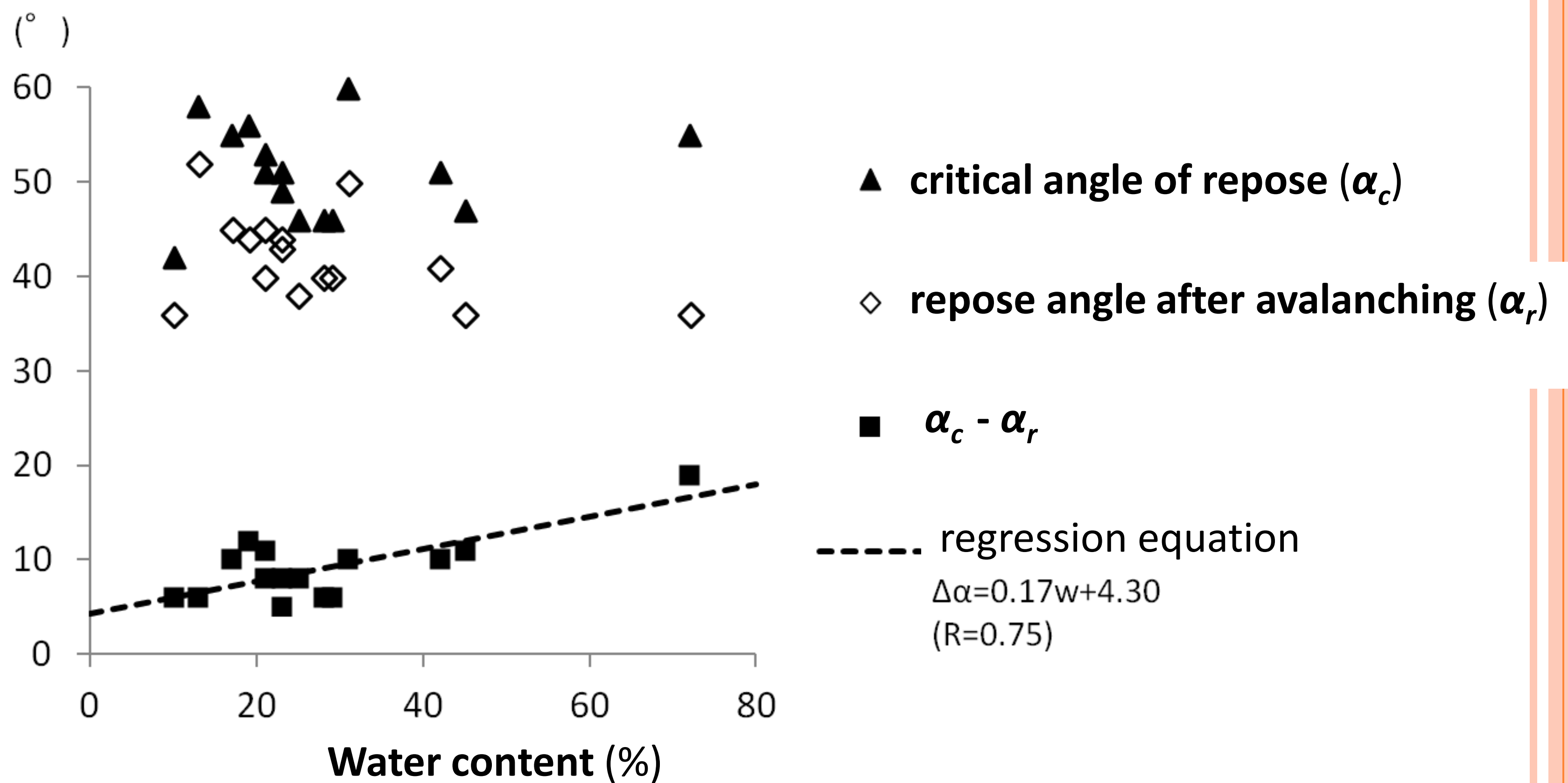
●*Repose angle after avalanching is almost equal to the angle of internal friction when the cohesion (**c**) obtained from the direct shear test is in the range of* $c \leqq 5$ *kN/m²*.

Critical angle of repose by landfill type



●*Landfill containing plastic waste with length of 10 cm or more, the repose angle, which indicates the stable inclination of the slope, increases considerably. The ground is fairly stable even when its slope is sharp.*

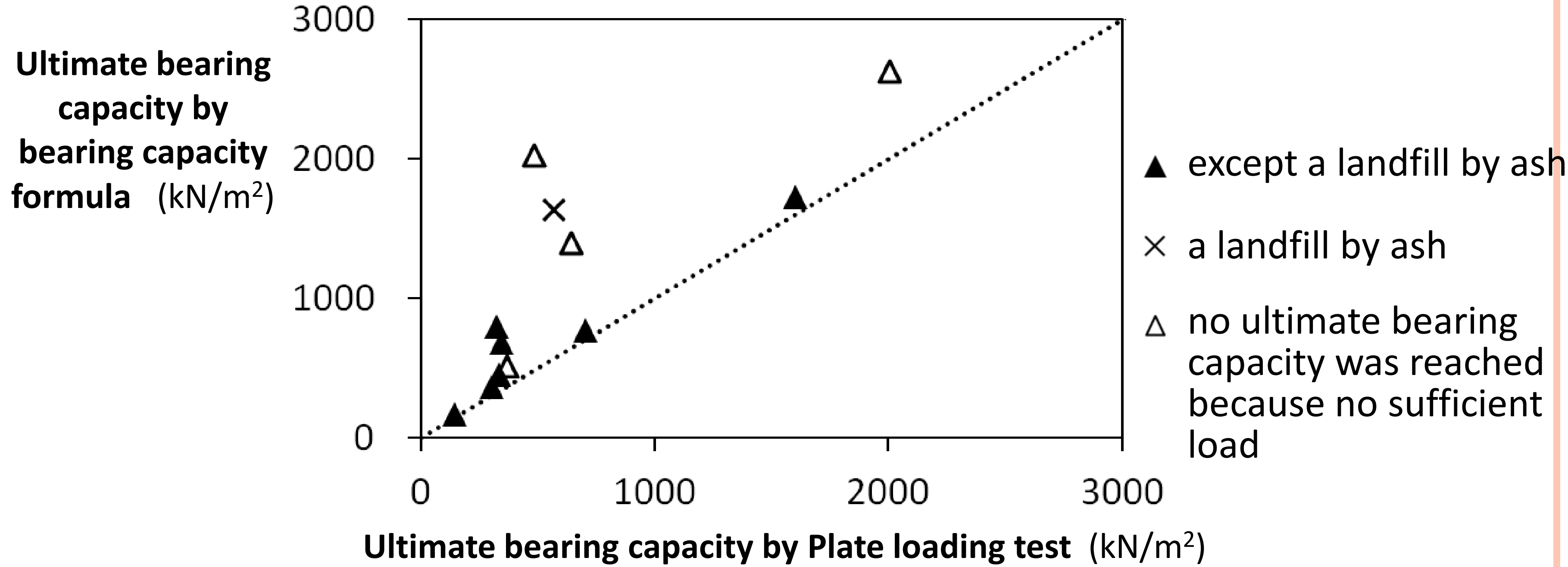
Relations between water content and repose angle



● *The higher is the water content, the bigger is the difference between the* ***critical angle of repose*** *and the* ***repose angle after avalanching****.*

● *If the* ***water content*** *of the ground increases for the reasons of dumping of* ***kitchen waste*** *and others, the repose angle after avalanching, which is the guide for actual* ***slope stability, diminishes considerably*** *by the reduction of friction resistance.*

Bearing capacities from Impact acceleration test and Repose angle test



Bearing capacity formula

$q_u = i_c \cdot \alpha \cdot c \cdot N_c(\varphi) + i_r \cdot \beta \cdot r_1 \cdot B \cdot \eta \cdot N_r(\varphi)$ ($\boldsymbol{q_u}$: **Ultimate bearing capacity**)

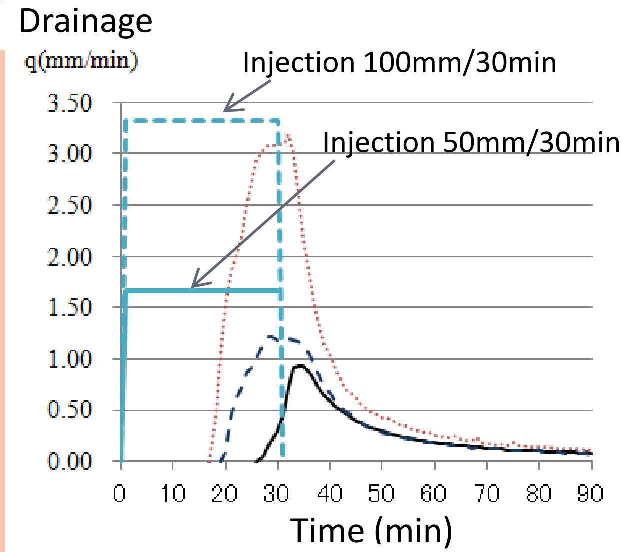
by Impact acceleration test

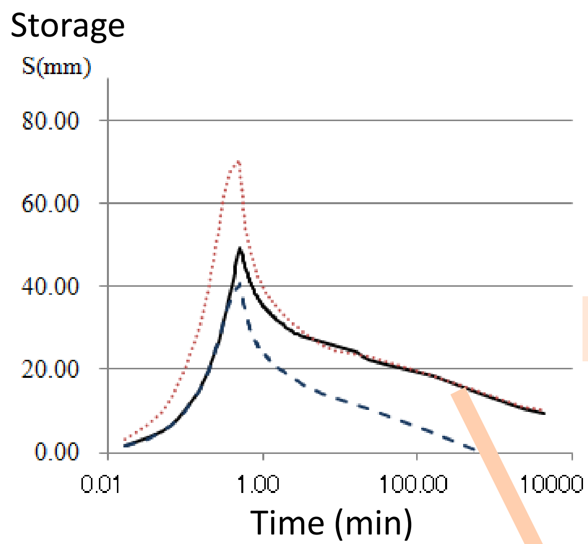
by Repose angle test

● *Ultimate bearing capacity found by the plate loading test and that calculated by substituting the **c** and **φ** obtained by the impact acceleration test and the repose angle test into the **bearing capacity formula** showed certain relations.*

● ***Impact acceleration test** and **repose angle test** are believed to be cost effective tests for preliminary determination of the bearing capacity in the early stage of land use project studies.*

5.5 Water behavior in the waste ground





Specimen (50mm/30min)

Specimen (100mm/30min)

2cm sieve pass (50mm/30min)

Result of column experiment (*t-q* and *t-S*)

Specimen from an inert waste landfill in Kanto district

Column experiment

Test pitting on an inert waste landfill

Pitting (h=2.6m) ending July 31, 2014 10:30

After 6 hours (July 31, 2014 16:50)
Water at a position 25 m higher than the internal water level

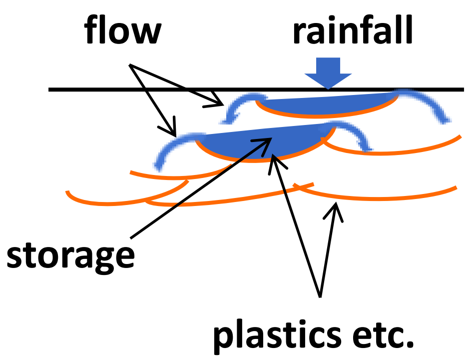


Illustration of flow in waste ground

Flow in waste ground can be expressed by **storage function**

$S = K \cdot q^p$

$dS/dt = q$

Provided, if $S > C$

$q = q_{in}$

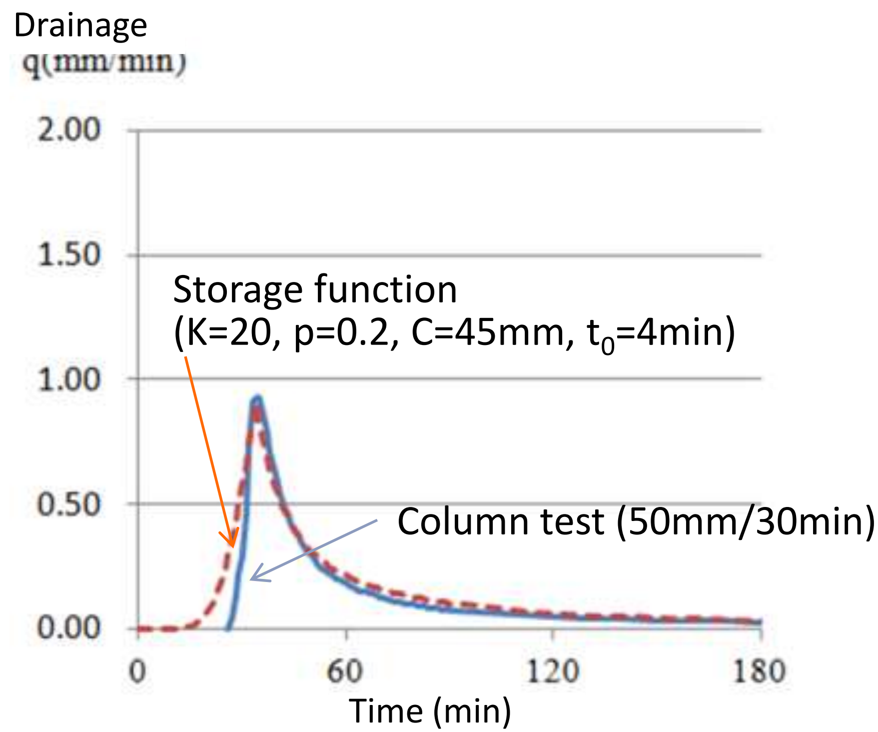
Where, S: Storage (height)(mm)

C: Internal storage capacity (height) (mm)

K, p: Storage function constant

q : Drainage (height)(mm)

q_{in}: Injection (height) (mm)



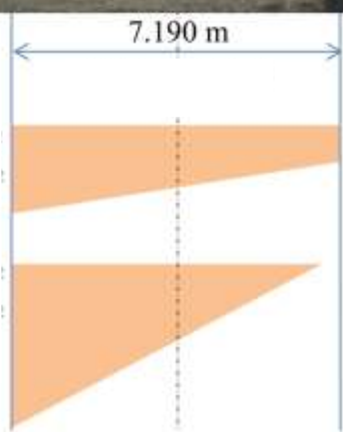
Comparison of column test data and result of storage function

●*Some rainwater is retained on the surface of plastics or the like inside the landfill for a rather long period of time and then flows down slowly.*
●***Storage function equations** reproduce the drainage fairly well, enabling analysis on site.*

5.6 On-site full-scale loading test

Concrete foundation on a landfill in Chubu district (7m in diameter, 1m thick)

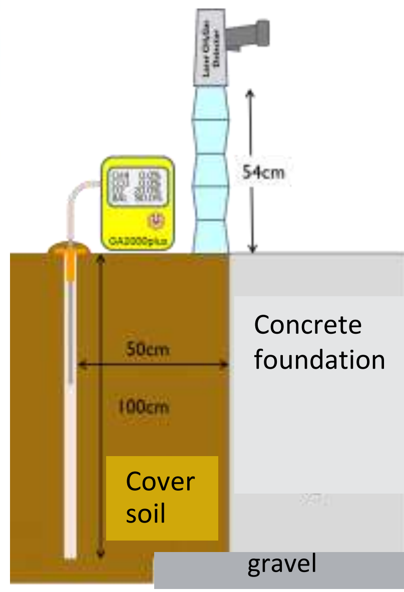
Eccentric load test (1.5 year deposit)



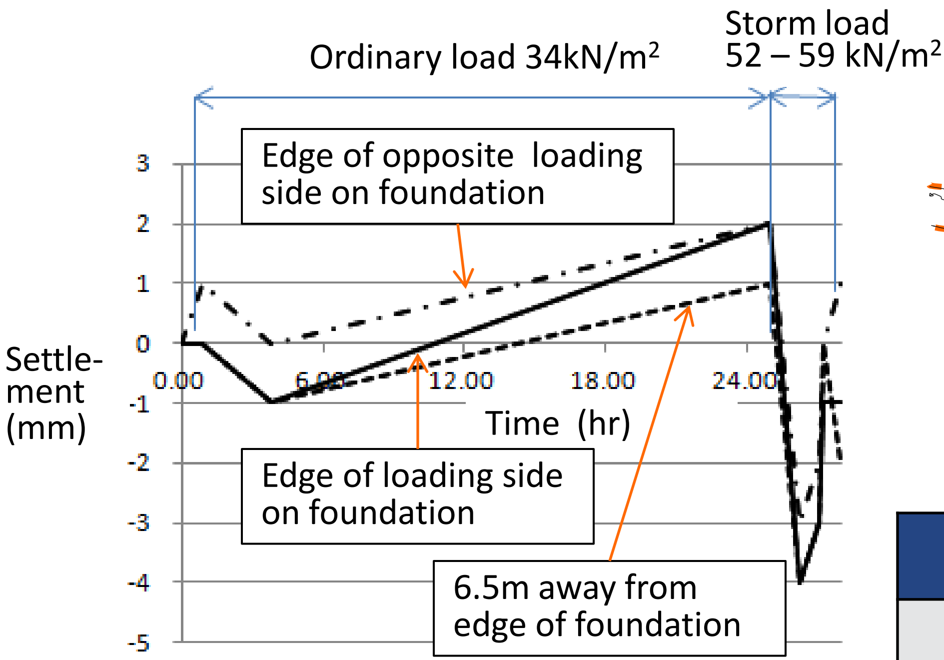
Ordinary load
Design 32.7kN/m²
Test 34.3kN/m²

Storm load
Design 50.9kN/m²
Test 58.7kN/m²

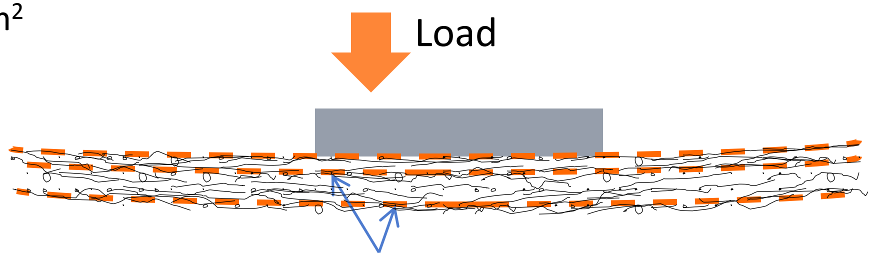
Generated gas test



Assumed small wind turbine
Weight ; 9.8 kN
Hub height ; 30m
Generation capacity; 10kW
(Excel10 by TenArrows)



Result of on-site full-scale loading test



Result of Generated gas test

Time	Location	CH_4	CO_2	H_2S
Before foundation	surface	ND	ND	ND
in Eccentric load test	0.5m away from edge of foundation	ND	ND	ND
	boundary	5～14ppm	------	------

●*The settlements were 4mm maximum on the foundation load side and 3mm on the opposite side. The settlement was almost even and no uneven settlement was observed. One likely reason for the absence of uneven settlement in the eccentric loading test is the presence of entangled plastics and others.*

●*There was no change in gas generation before and after the loading test, but a slight methane was generated from the boundary between the concrete foundation and the cover soil.*

6. Conclusions

● Landfills containing long plastics and like materials are soft and prone to settlement, but they have **large friction resistance** and unique **tensile resistance**, both of which contribute to their **high slope stability** and generally larger ultimate bearing capacity than common earth landfills.

● Meanwhile, the repose angle test suggested that landfills which have high, near-**saturation water content** have considerably **poor slope stability**.

● **Repose angle test** was found to provide a good guide to assessing the slope stability, and the simple **on-site test methods of impact acceleration** and repose angle enable **estimation of the ultimate bearing capacity**.

Thank you !

In front of a landfill in Turkey.

Contact's e-mail address ; yamawaki@sanpainet.or.jp