# Pore water pressure estimation method at the time of the collapse using a Soil Strength Probe

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**Abstract**

Process of shallow landslides have not yet been clarified. Slope stabilization measures have usually been done after the collapse. However, it is desired that they be carried out before the collapse. Before the collapse, if we understand the structure of the strata, the strength of the soil, and the pore water pressure, we will be able to do the appropriate slope stabilization measures. In practice, there are two factors that prevent them. (1) Difficulties of measuring the strength of the soil in situ. (2) Difficulties of pore water pressure measurement of the moment of collapse. In places that have not yet collapse, when c (cohesion), ∅ (internal friction angle), and u (pore water pressure) can be measured, we can deductively calculate the safety factor (Fs). In the collapsed place, if we know c and ∅, we can be back-calculated the pore water pressure at the time of collapse. New tool that can easily measure the c and ∅ in the field, is a Soil Strength Probe (SSP,or "DOKENBO" in Japanese). In some cases of the slope collapses, inverse analysis results of pore water pressure are often pressured hydraulic head.

**Keywords**: pore water pressure, Soil Strength Probe, DOKENBO, shallow landslide

## 1. Introduction

Stability of slopes is usually evaluated by the factor of safety. The factor of safety is defined as the ratio of the shear strength divided by the shear stress required for equilibrium of the slope. Limit equilibrium analysis requires information about the strength of soil, and pore water pressure. The newly developed soil strength tests, Soil Strength Probe Test (SSPT) can measure topsoil thickness and soil strength (cohesion and internal friction angle) of topsoil. On-site permeability test of topsoil and seepage analysis provide the water table in some condition of precipitation. Using those coefficients, the safety factor should be able to be computed, and the reappearance computation of the collapse, too. However, often, it didn't become so. I think that the reasons for the mistake were miss-evaluation with water pressure.

At this article, I will show the mechanism of shallow landslides and propose an appropriate mitigations.

## 2. Factor of safety and on-site tests

The factor of safety is defined by Equation1 and 2.

$$\mathrm{Fs} = \frac{shear\ strength}{shear\ stress\ required\ for\ equilibrium} \quad (1)$$

$$= \frac{c' + (\sigma - u)\tan\emptyset'}{\tau}$$

in which

Fs = factor of safety

c′ = cohesion

∅′ = angle of internal friction

u = pore water pressure

σ = normal stress on slip surface, and

τ = shear stress required for equilibrium

Both the topsoil thickness and cohesive, frictional components of strength (c′ and∅′) can measure by SSPT(fig.1, 2 and 3).

On-site unit weight test using circular cylinder sampling shows in fig.4.

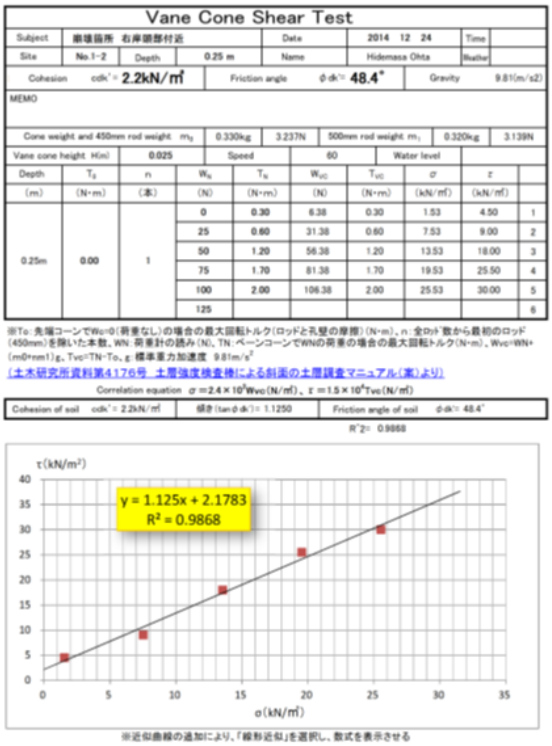
Water table (pore water pressure) is computed by seepage analysis (FEM) using on-site permeability test (fig.5 and 6).

Topographical survey using reflectorless laser measurement tool shows in fig.7.

Thus all components for calculating Fs can be measured easily by newly developed on-site tools. And the safety factor should be able to be computed deductively.

Therefore by using these methods, it should be possible to evaluate the stability of the slope before the collapse.


Fig.1 On -site Soil Strength Probe Test (SSPT)



| Vane Cone Shear Test | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Subject | 崩壊箇所 右岸頭部付近 | | | Date | 2014 12 24 | | Time | | |
| Site | No.1-2 | Depth | 0.25 m | Name | Hidemasa Ohta | | Weather | | |
| Cohesion | cdk' = 2.2kN/㎡ | | Friction angle | φdk' = 48.4° | | | Gravity | 9.81(m/s2) | |
| MEMO | | | | | | | | | |
| Cone weight and 450mm rod weight $m_0$ | | | 0.330kg | 3.237N | 500mm rod weight $m_1$ | | 0.320kg | 3.139N | |
| Vane cone height H(m) | | 0.025 | | Speed | 60 | | Water level | | |
| Depth | $T_0$ | n | $W_N$ | $T_N$ | $W_{VC}$ | $T_{VC}$ | σ | τ | |
| (m) | (N·m) | (本) | (N) | (N·m) | (N) | (N·m) | (kN/㎡) | (kN/㎡) | |
| 0.25m | 0.00 | 1 | 0 | 0.30 | 6.38 | 0.30 | 1.53 | 4.50 | 1 |
| | | | 25 | 0.60 | 31.38 | 0.60 | 7.53 | 9.00 | 2 |
| | | | 50 | 1.20 | 56.38 | 1.20 | 13.53 | 18.00 | 3 |
| | | | 75 | 1.70 | 81.38 | 1.70 | 19.53 | 25.50 | 4 |
| | | | 100 | 2.00 | 106.38 | 2.00 | 25.53 | 30.00 | 5 |
| | | | 125 | | | | | | 6 |

※To: 先端コーンでWc=0(荷重なし)の場合の最大回転トルク(ロッドと孔壁の摩擦)(N·m)、n: 全ロッド数から最初のロッド(450mm)を除いた本数、WN: 荷重計の読み(N)、TN: ベーンコーンでWNの荷重の場合の最大回転トルク(N·m)、Wvc=WN+(m0+mm1)g、Tvc=TN-To、g: 標準重力加速度 9.81m/s²

(土木研究所資料第4176号 土層強度検査棒による斜面の土層調査マニュアル(案)より)

Correlation equation $\sigma = 2.4\times10^3 W_{vc}$ (N/㎡)、$\tau = 1.5\times10^4 T_{vc}$ (N/㎡)

| | | |
|---|---|---|
| Cohesion of soil cdk' = 2.2kN/㎡ | 傾き(tanφdk') = 1.1250 | Friction angle of soil φdk' = 48.4° |

R^2= 0.9868



Fig.3 Examples of the SSPT data sheet

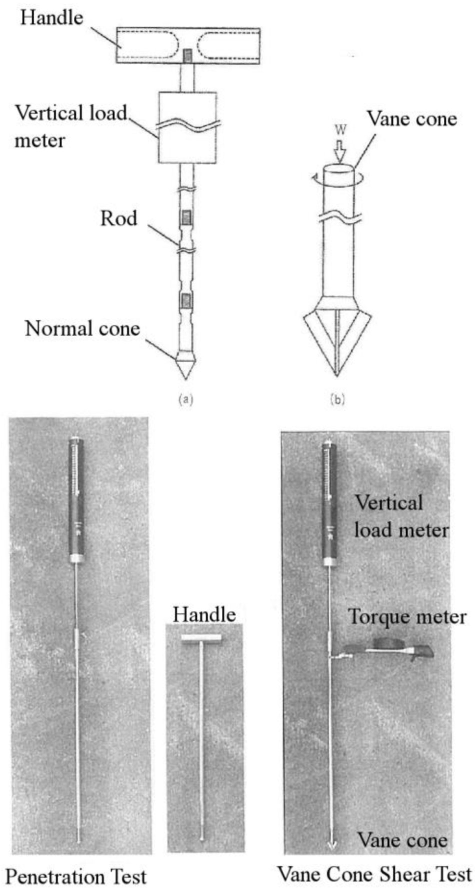



Fig.2 Structure of Soil Strength Probe (SSP)


Fig.4 Unit weight test using circular cylinder

Fig.5 On-site permeability test

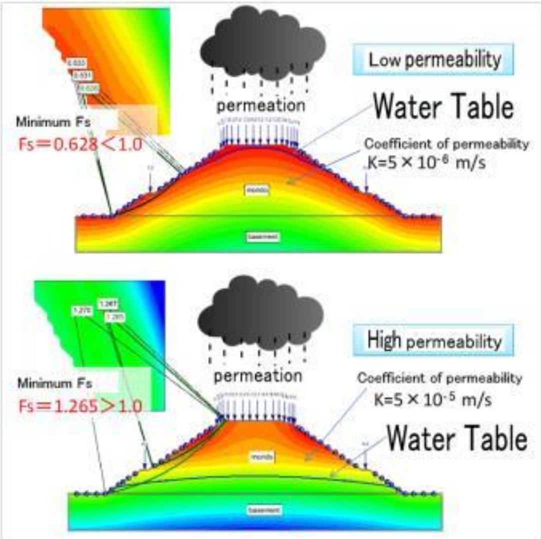



Fig.6 Examples of seepage analysis using coefficient of on-site permeability

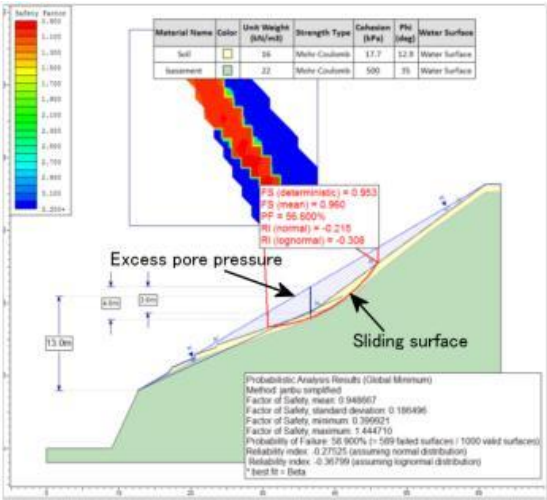
Fig.7 Topographical survey using reflectorless laser measurement tool

## 3. Pore water pressure problem

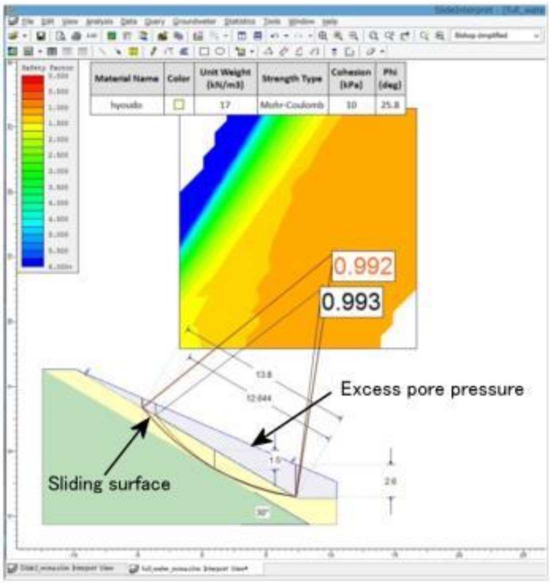
In several collapse locations, I tried to reproduce the safety factors, and I got some results that are not expected.

Even when the groundwater level the same as the ground surface, computed Fs values using all the components except for the coefficient of permeability, were often greater than 1.

When Fs values were calculated to be less than 1, groundwater head was higher than the ground surface. In other words, underground water pressure, had become excess pore water pressure state (fig.8).




(a) Inverse analysis, Yokosuka 2012




(b) Inverse analysis, 30 degree inclined slope

Fig.8 Examples of inverse analysis

Computed water pressure at the time of collapse. Interestingly, high water pressure slope, had no small collapse marks. Apparently, they were small risk slopes. Therefore, they had not been monitored.

### 3.1 Evidence of high water pressure at the time of collapse

The traces which the very high water pressure acted on were left in the scene where the slope collapsed in the heavy rain (fig.9 and 10). In this way, the excess pore water pressure is related to the slope collapse strongly.


Fig.9 Hishikari, Kagoshima 2003 landslide
Big hole in collapse surface, large rock that was blown off by very high water pressure


Fig.10 Shobara, Hiroshima 2010 landslide
Circular collapse, Soil was blown away by very high water pressure

### 4. Effective preventive measures

When the collapse due to heavy rain occurs, I believe that the main cause of the collapse is high groundwater pressure.

Therefore, an effective preventive measures is a dissipation of high water pressure. For example, pipe drain method has its characteristics (fig.11).


### 5. Conclusions

(1) The strength test using the SSP, we can easily calculate the water pressure at the time of the collapse.
(2) At the time of the collapse, very large excess pore water pressure occurs.
(3) To prevent collapse, it is effective to dissipate high excess pore water pressure. (For example, pipe drain method)