MIDAS CONSTRUCTION TECHNICAL DOCUMENT COLLECTION

動解析・液状化分野 10

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動解析・液状化分野

10.

Landslide monitoring and early warning

公益社団法人地盤工学会　東畑 郁生 元会長

Landslide monitoring and early warning

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VP for Asia of ISSMGE
President of Japanese Geotechnical Society
Staying in Auckland with Seelye Fellowship

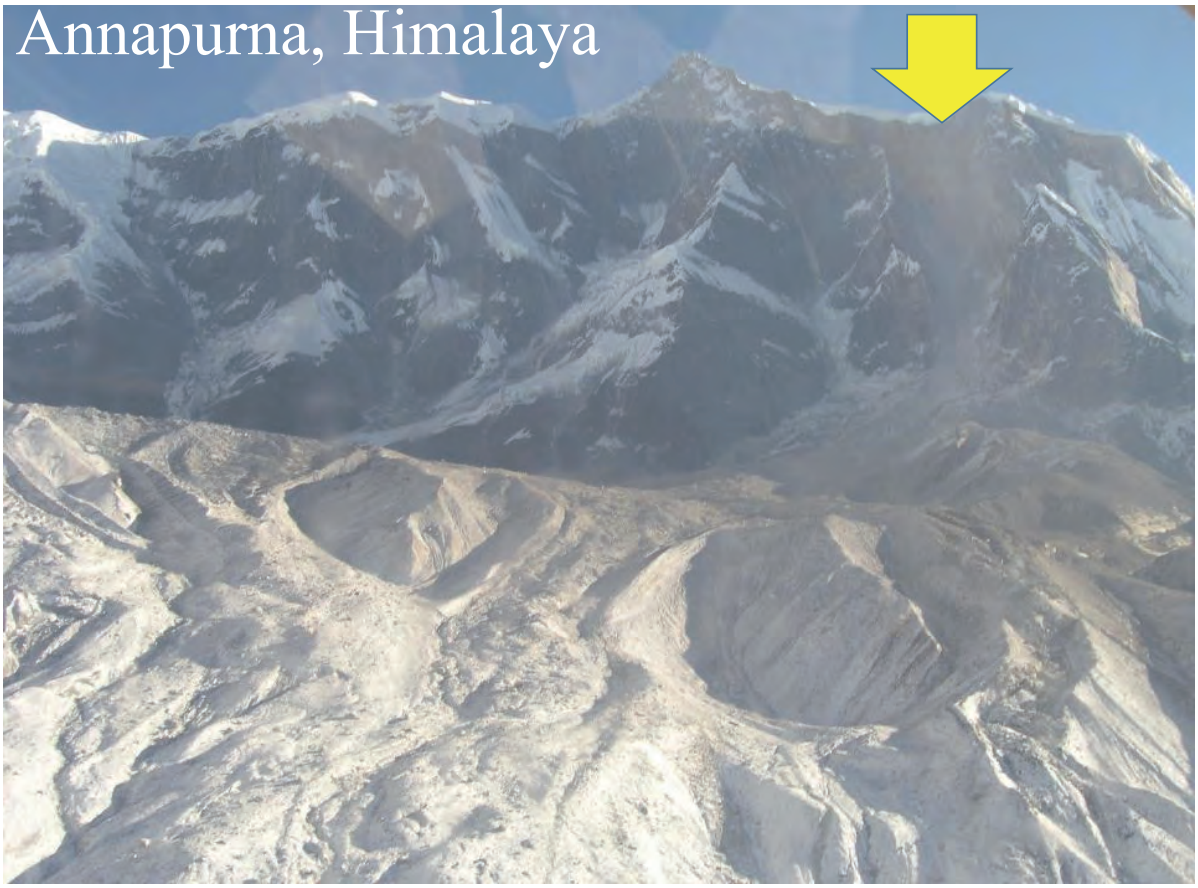
Acknowledgment to financial supports by the Ministry of Education (MEXT), Tokyo Metropolitan Government, Izu Oshima Municipal Government, Satoshi Goto, Wang Ling and Taro Uchimura among many others.

Slope disaster caused by heavy rain:

Weak geology in Nepal that I saw during my previous visit in 2012:

At Cohsmel between Pokhara and Lumbini;
Himalayan tectonic action has ruptured rocks

Disturbed slope after big earthquake and repeated debris flows; Sichuan Province, China

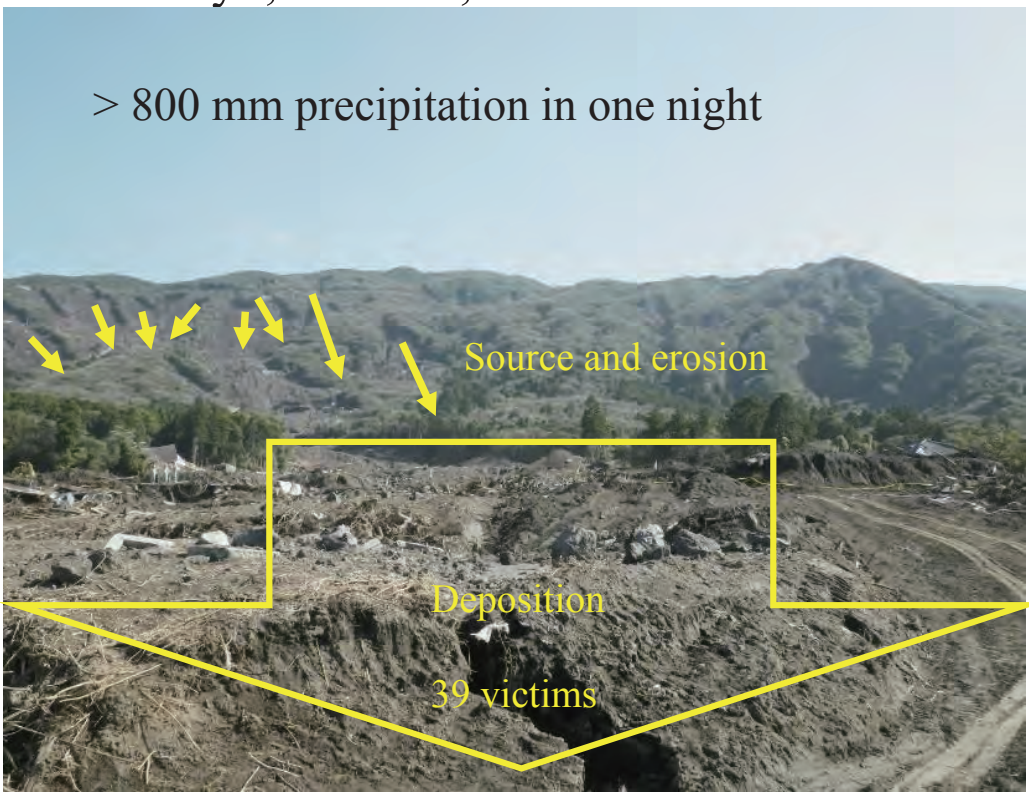


Contents

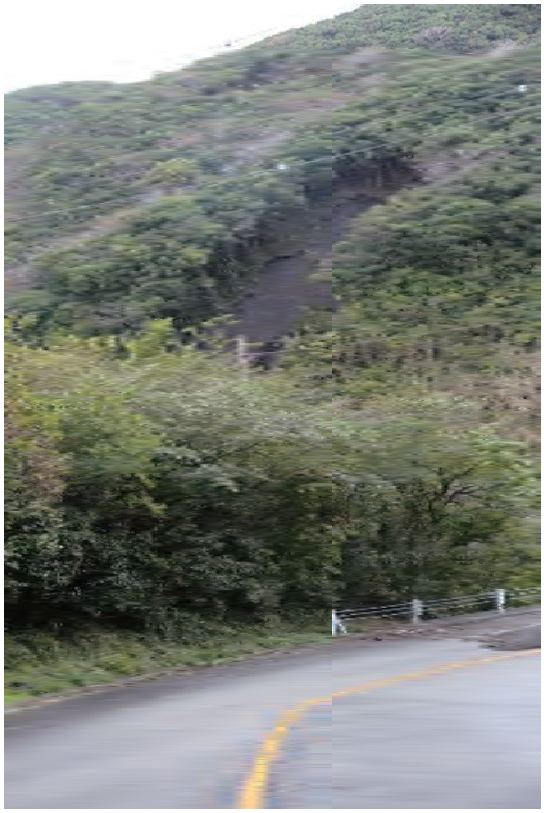
1. Recent slope disasters: Izu Oshima volcanic island
2. Mechanism of slope failure
3. Device for early warning
4. Difficulty in early warning

October 15-16, 2013
More than 800 mm in one night.
Rainfall concentrated in a small island → out of regional disaster warning.
Typhoon passed slowly near the island.

Rainfall-induced slope failure: Izu Oshima volcanic island near Tokyo, October, 2013.



Initiated by shallow failures but evolved to a bigger size by erosion



Very thin failed layer

Piping holes: mechanism of slope failure?

Erosion in the middle part of the slope
→ increased volume of soil flow

Destroyed town

Rainfall induced slope failure

Taiwan, 2011

Heavy rain
Slope failure
Debris flow
Bridge and bus were washed out

Issues of importance

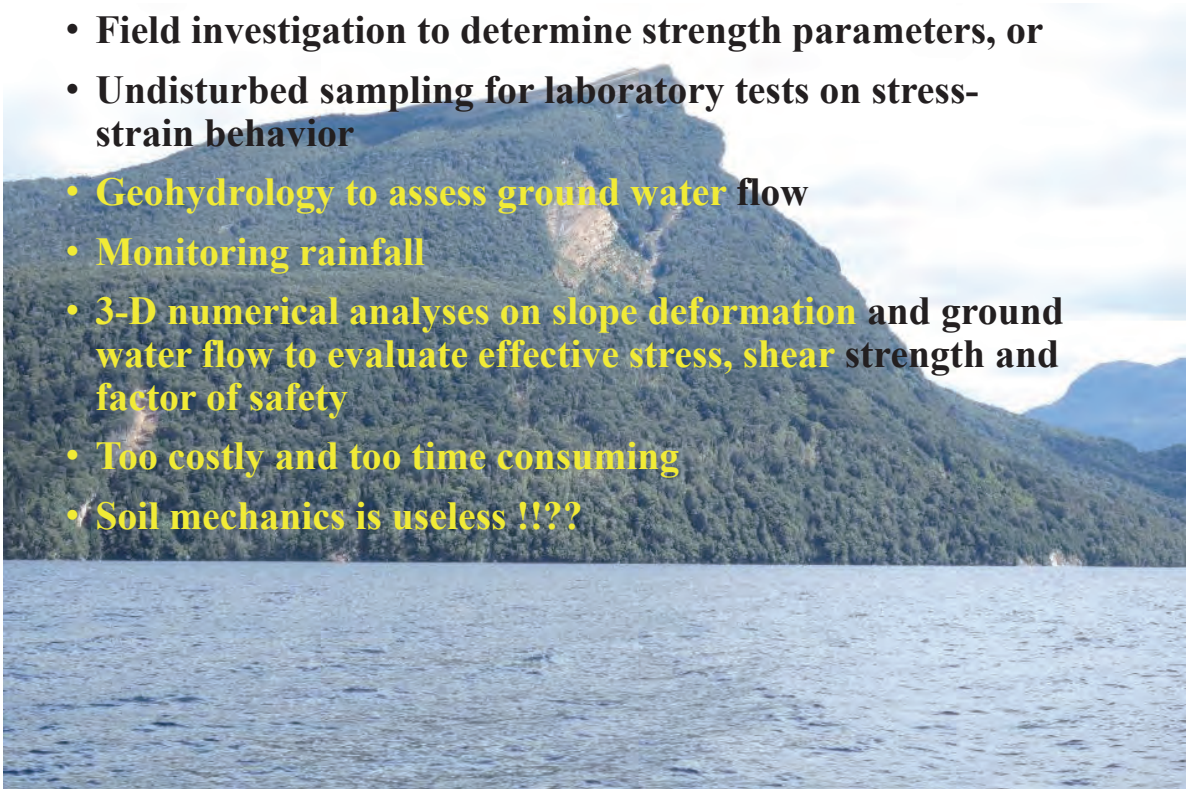
- Slope failure and d
- Inexpensive mitiga
- Warning in TV bas
  practiced but no co
  slope geometry
  → not effective fo
- Monitoring a parti
- Detect minor defo
- Install many low-c
  do not know which

Kinds of landslide mitigation

Human life is saved by these.

- Prevent landslide by Retaining wall, ground anchorage, drainage etc.; expensive
- Reduction of damage by relocation (people may not like this) and/or evacuation (early warning; property may be lost).
- Post disaster recovery: all are lost but let's re-start.

Soil-mechanic approach to early warning of slope failure during heavy rain

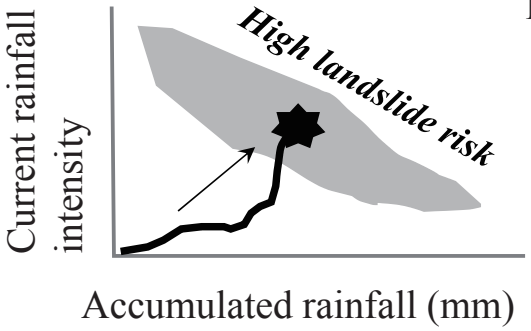


- **Field investigation to determine strength parameters, or**
- **Undisturbed sampling for laboratory tests on stress-strain behavior**
- **Geohydrology to assess ground water flow**
- **Monitoring rainfall**
- **3-D numerical analyses on slope deformation and ground water flow to evaluate effective stress, shear strength and factor of safety**
- **Too costly and too time consuming**
- **Soil mechanics is useless !!??**

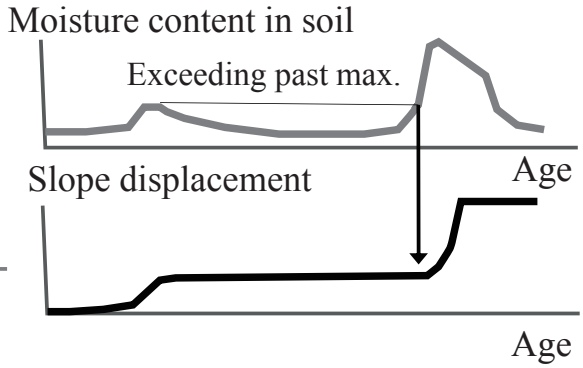
Two kinds of early warning methodology

1. Rainfall record criterion

1) Current rainfall intensity;
e.g. in the past 3 hours (mm)



2) Ever highest moisture content in soil triggers slope failure.



2. Displacement criterion

Monitoring displacement or else by extensometers, GPS or else.

If displacement time history reaches some critical level, warning is issued for evacuation.

Shallow slope failure is focused on

Kita-nigoro, Tochio, 2004

Sliding of surface weathered material.

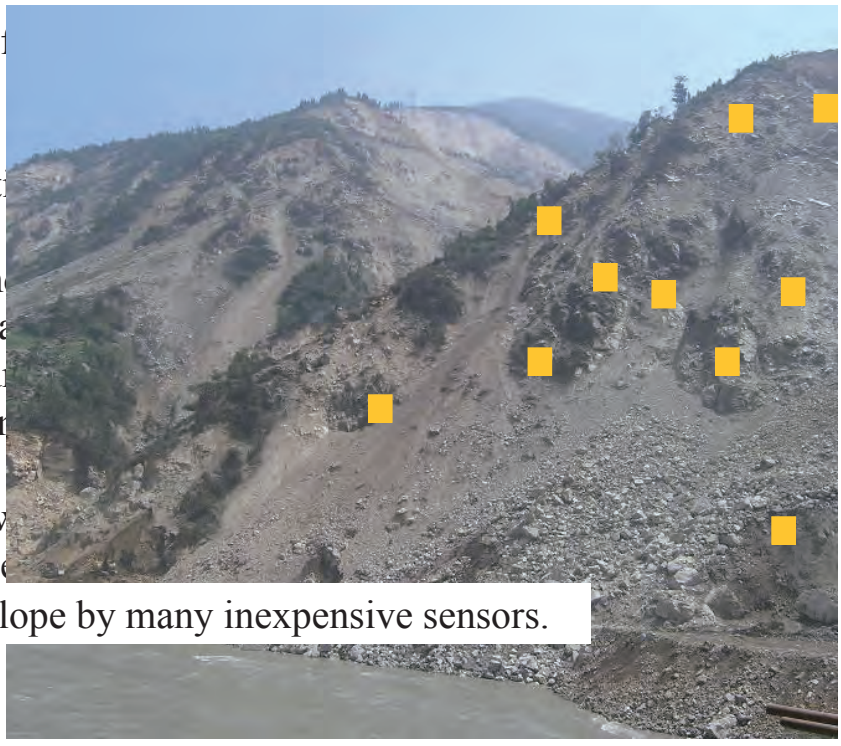
Small in scale but many in number.

Where tree roots are shallow, the entire surface soil is lost during heavy rain.

Basic philosophy of early warning

Typical precursors of
- Surface crack
- Roaring sound
- Sound of root cutti
- Water boiling and

◆ All suggest groun
◆ It is difficult to wa
rain or record sou
◆ Alternative idea: r
sensor.
◆ We do not know w
know where the se
◆ Cover the entire slope by many inexpensive sensors.



Many inexpensive sensors cover a slope.

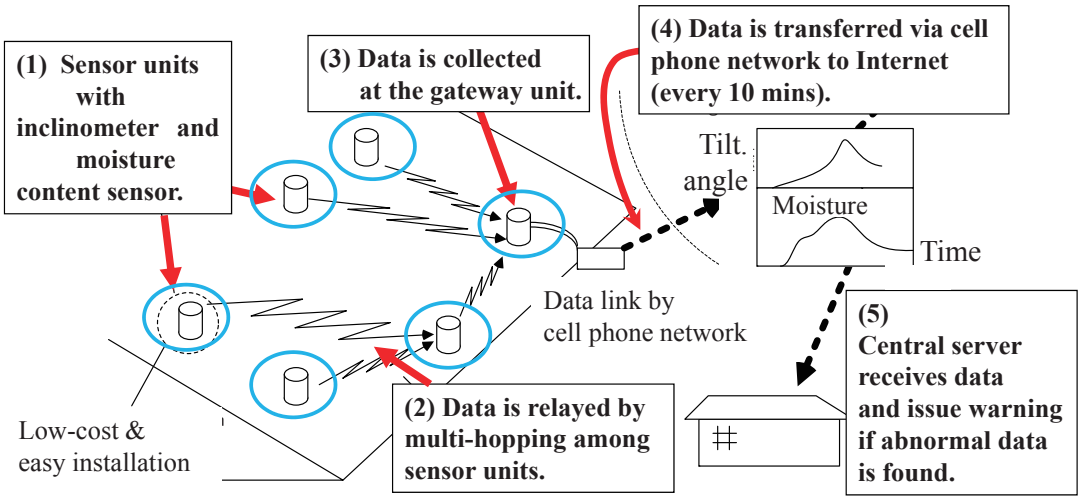


Fig. 1 Structure of the proposed wireless monitoring and early warning system

Tiltosensor to detect the minor deformation; now US 200 $

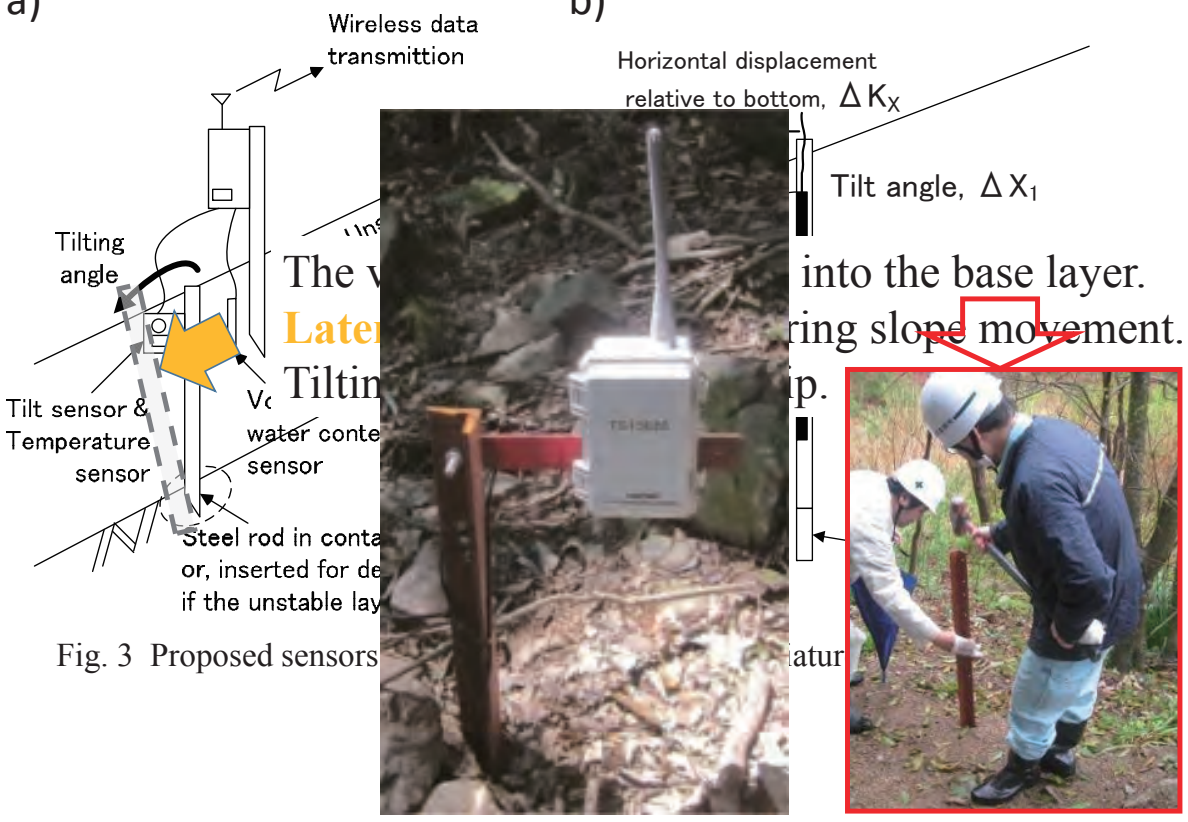


Fig. 3 Proposed sensors

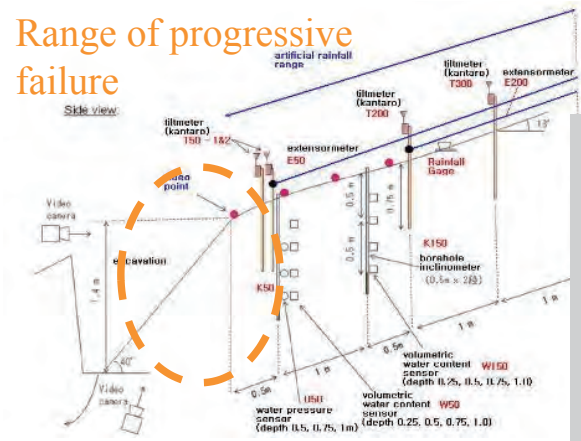
Validation of technology by field monitoring

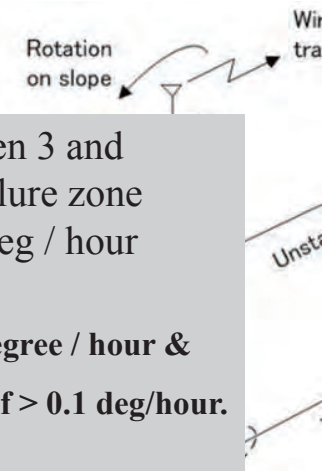
Current proposal: Caution if rate of angle > 0.005degree / hour &

Alert / Evacuation if > 0.1 deg/hour.

Artificial rainfall test in Sichuan Province, China

Range of progressive failure



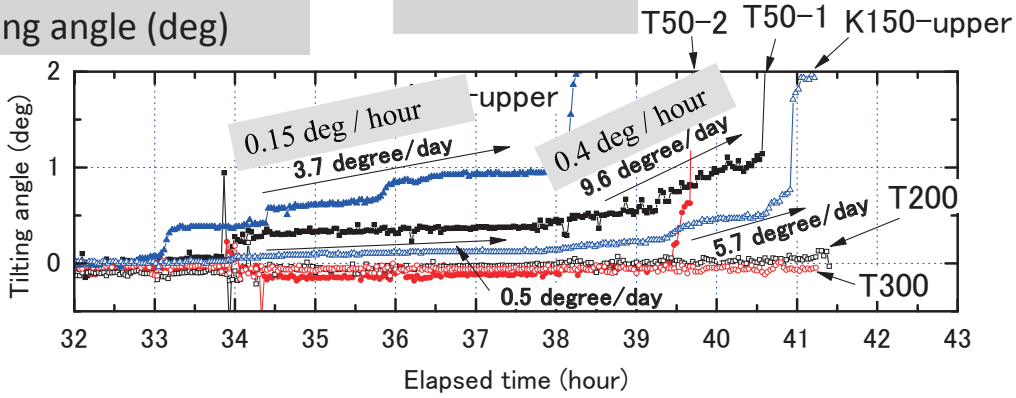


Tilting rate between 3 and 10 deg/day in failure zone = 0.12 and 0.4 deg / hour

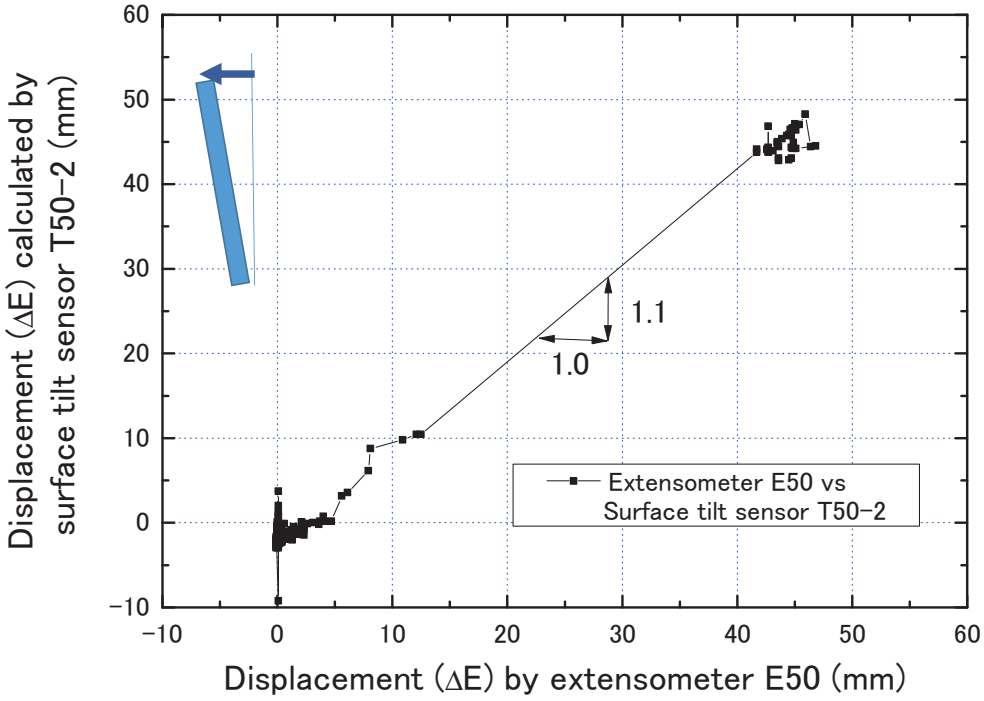
Caution if > 0.005degree / hour &

Alert / Evacuation if > 0.1 deg/hour.

Tilting angle (deg)

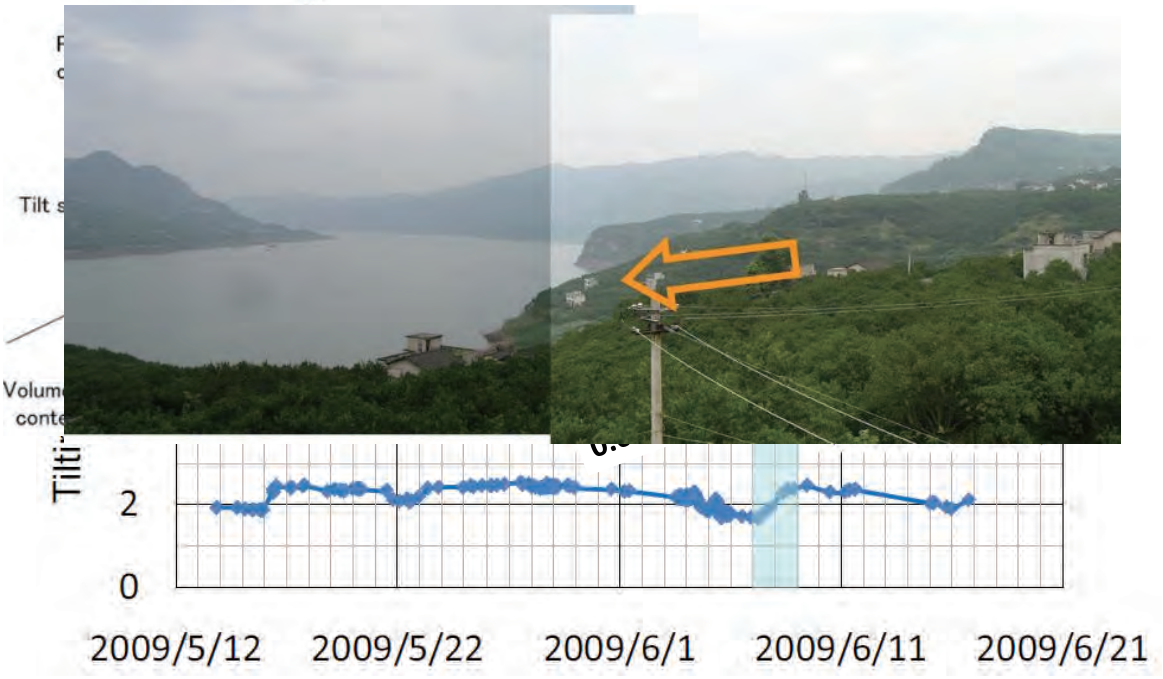


Tilting angle * length of vertical rod = lateral displacement.
It is equivalent with the data from a conventional (more expensive) extensometer.



Along Three Gorge Dam Reservoir, China, many landslides were going on during filling water.

Monitored tilting angle in Three Gorges Dam Landslide Area



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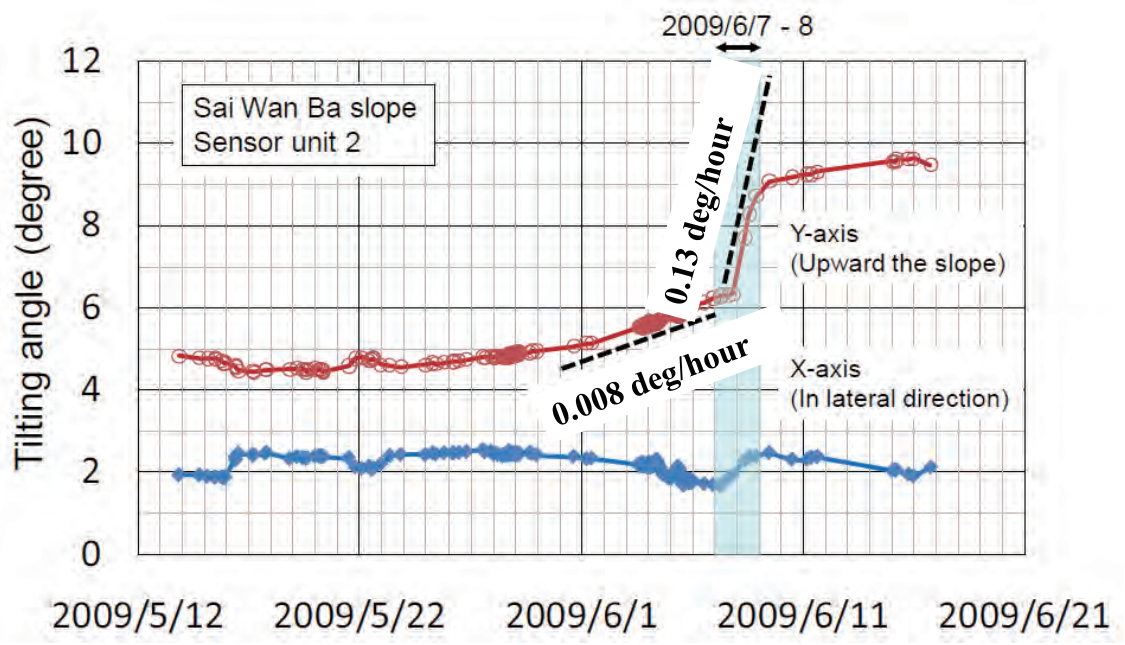
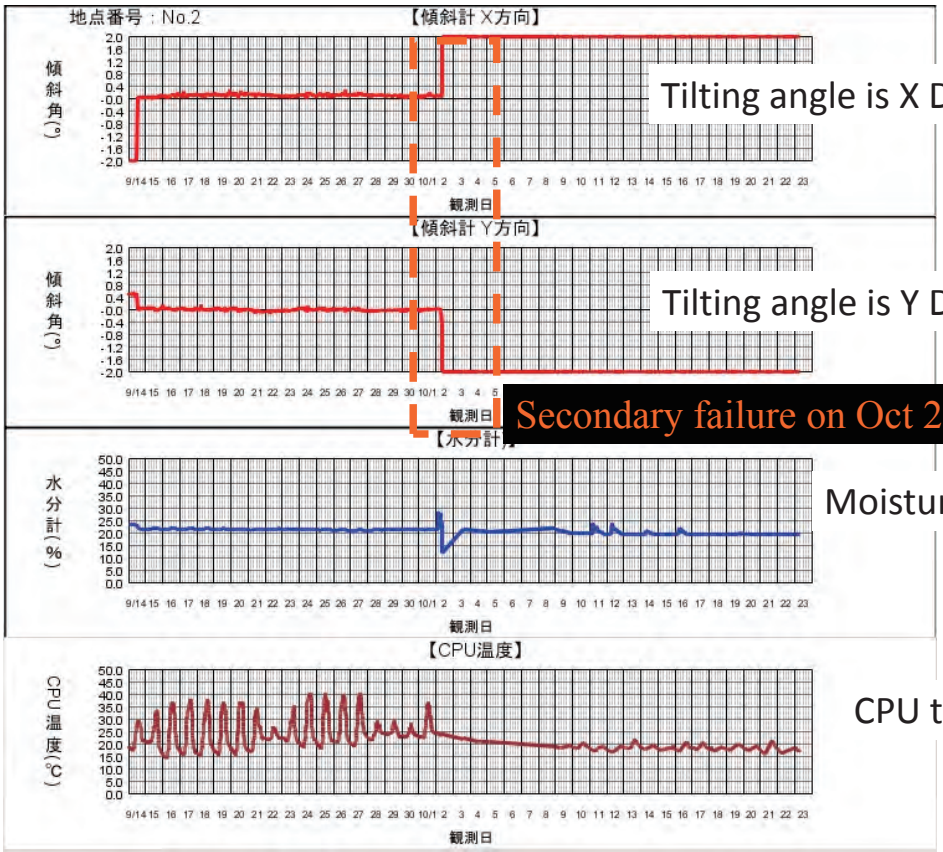
Monitored tilting angle in Three Gorges Dam Landslide Area



Current proposal: **Caution** if rate of angle > 0.005degree / hour &

Alert / Evacuation if > 0.1 deg/hour.

After the first failure in July 2009:



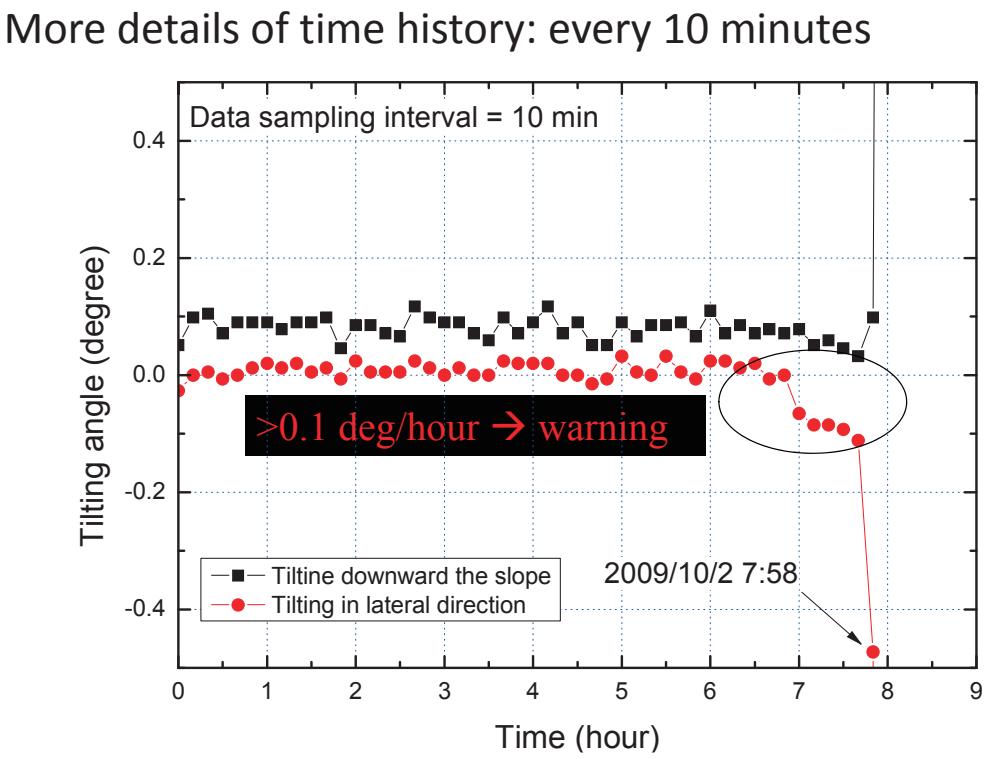
Tilting angle is X Direction

Tilting angle is Y Direction

Secondary failure on Oct 2.

Moisture content

CPU temperature



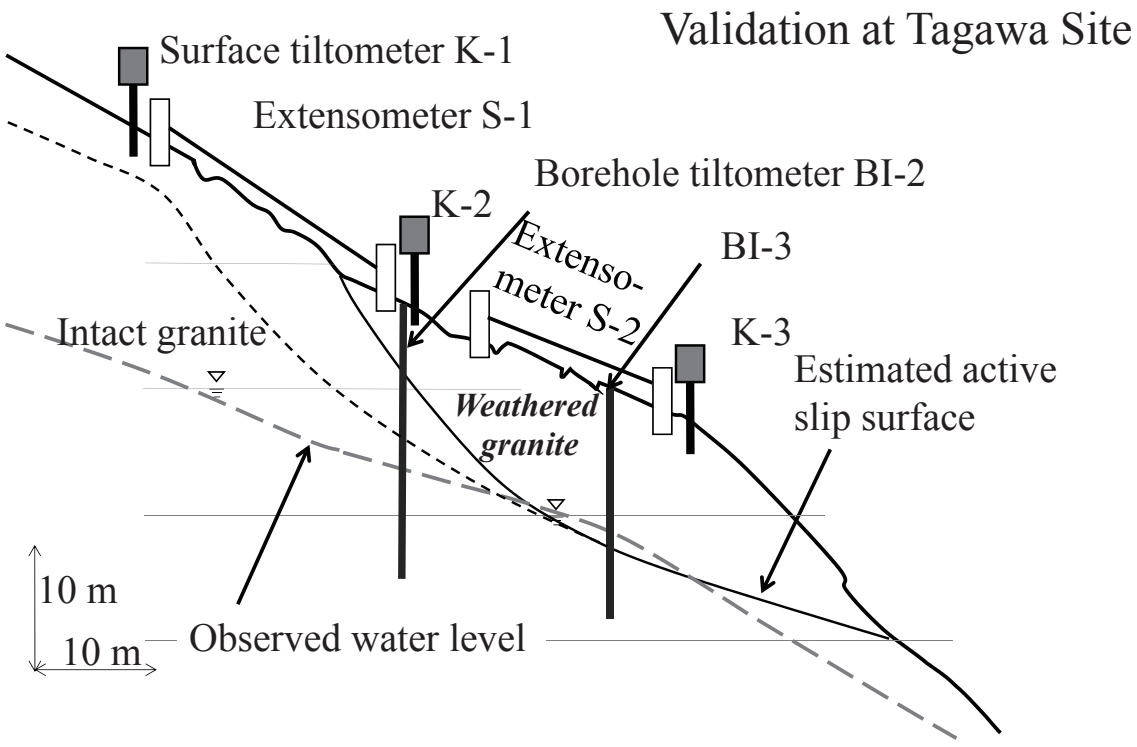
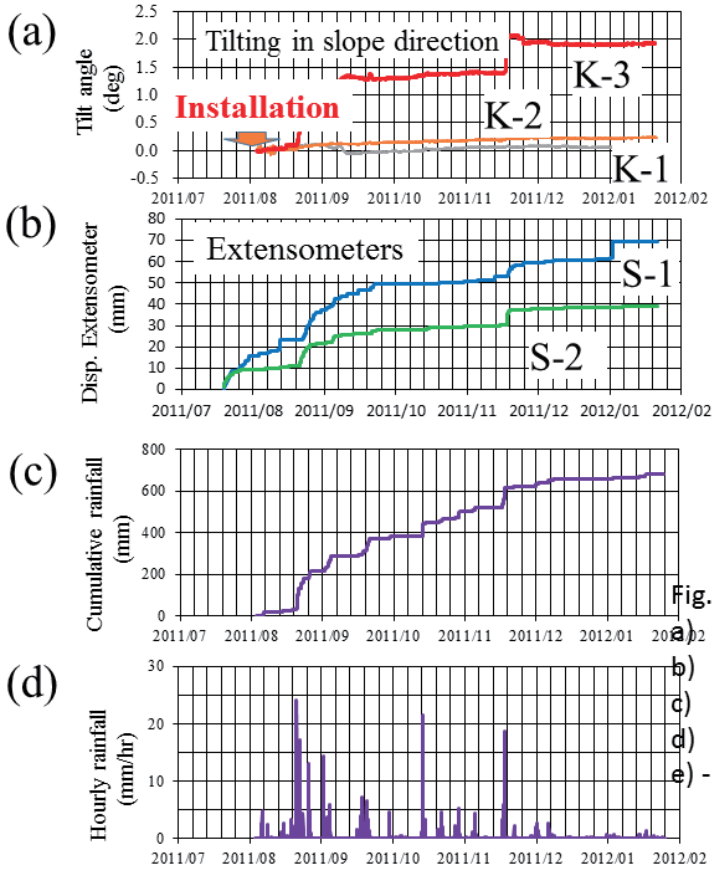
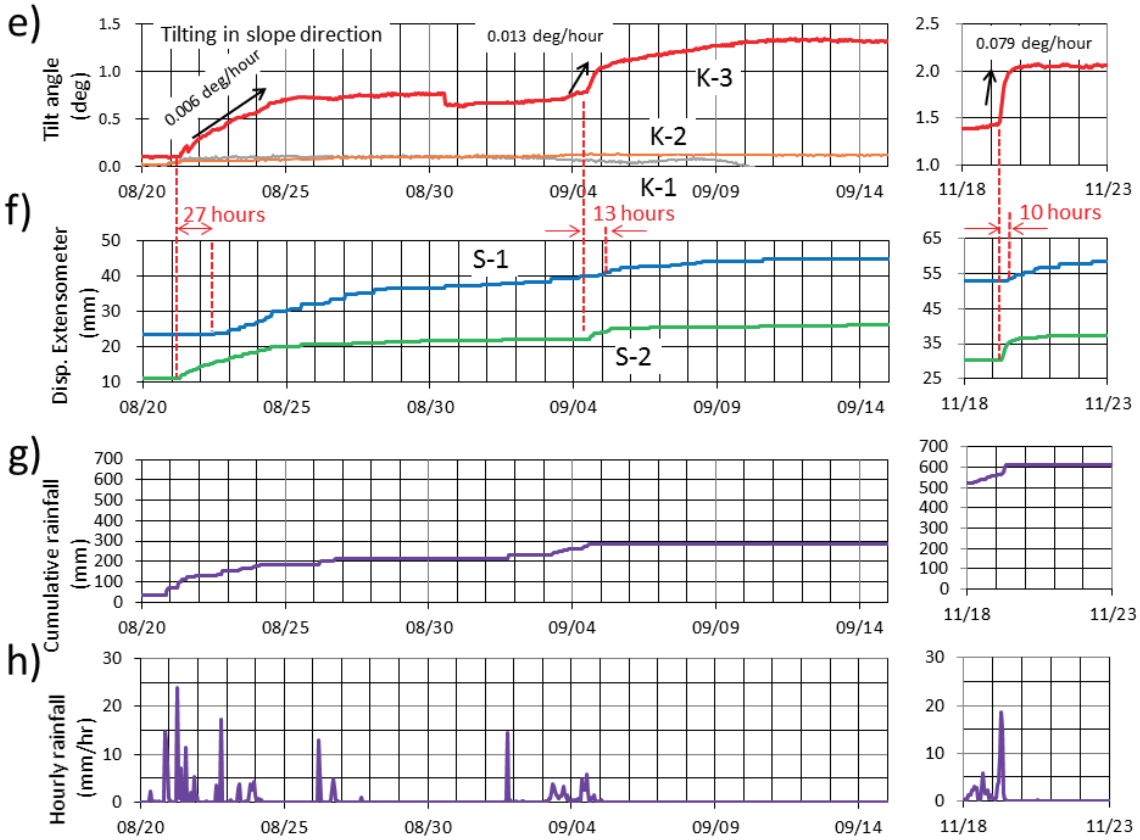


Fig. 17 Site of long-term monitoring along national road



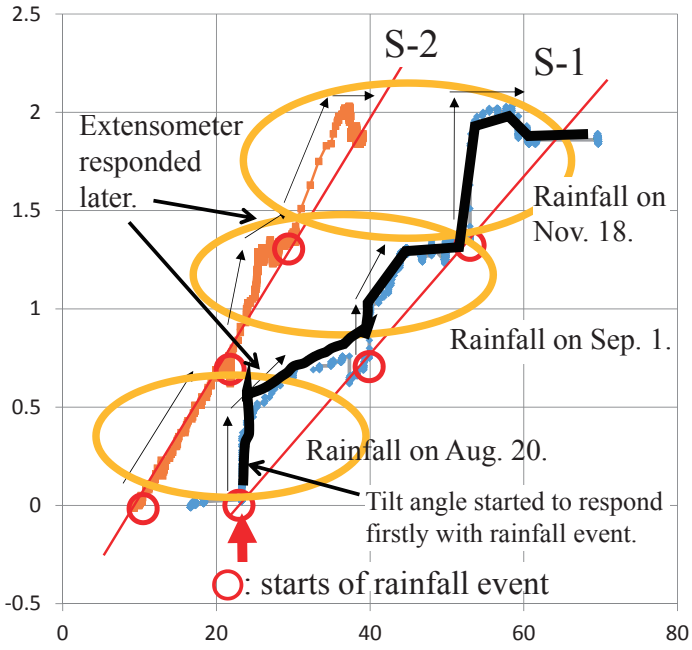
Extensometers started recording on Jul. 19, while tilt sensors started recording on Aug. 3.

Fig. 18 Time histories of monitored items:
a) Tilt angles by surface tilt sensors;
b) Displacements by extensometers;
c) Accumulated amount of rain;
d) Rainfall intensity;
e) - h) Zoom up for heavy rainfall events.



Extensometers started recording on Jul. 19,
while tilt sensors started recording on Aug. 3.

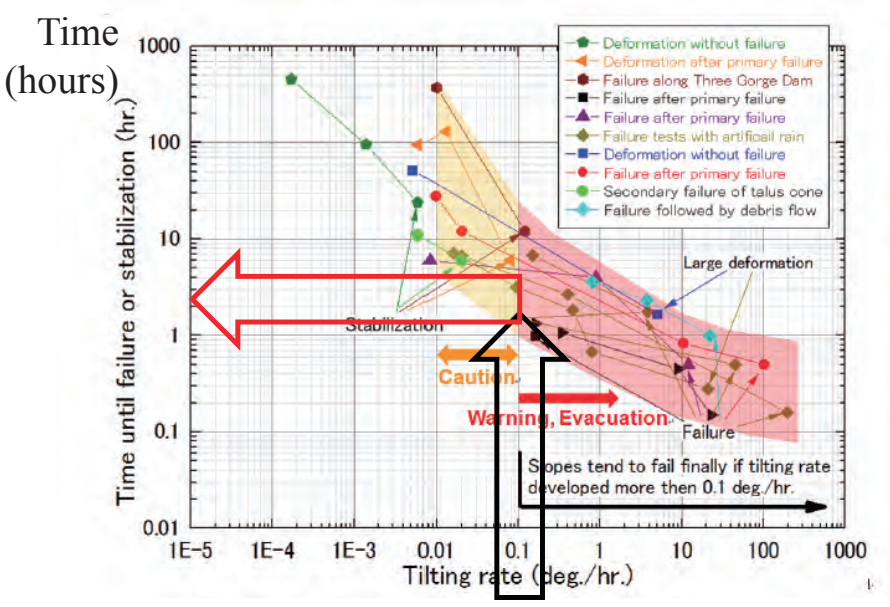
Tilting angle, K-3 (deg)



Displacement along extensometer, S-1 and S-2 (mm)

Tiltometer responded prior to extensometer response.

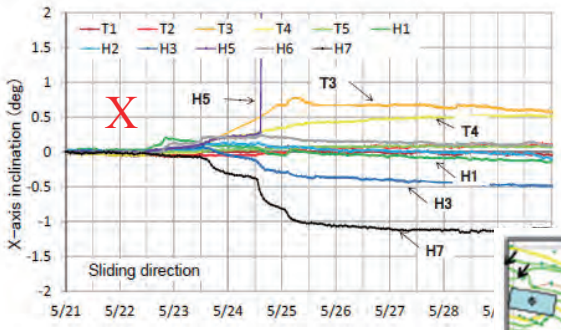
Relationship between monitored rate of tilting and time until final failure

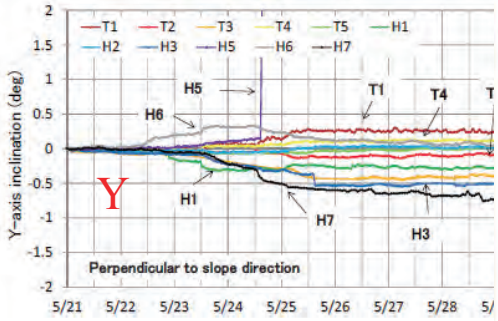


Attempts for multi-point monitoring (in Taiwan)

Records of tilting angle in X and Y directions

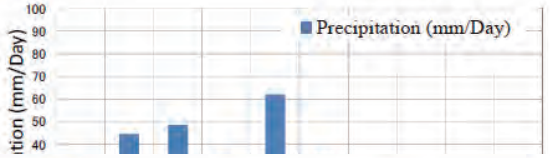
May 2015

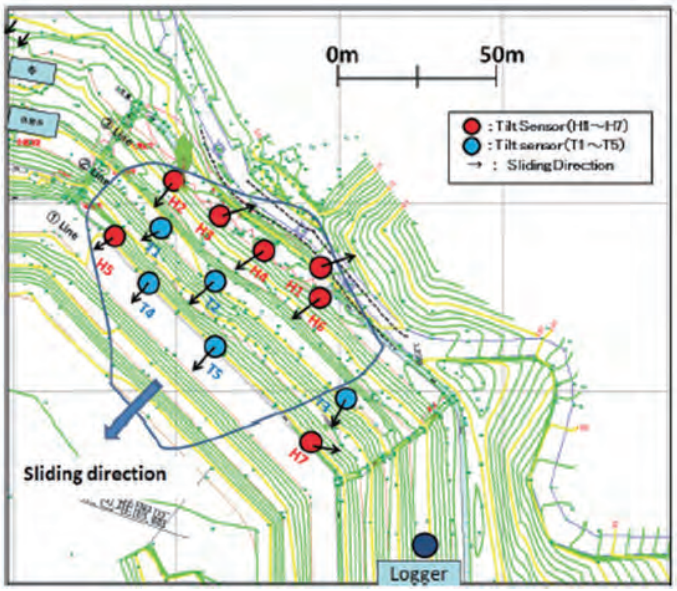




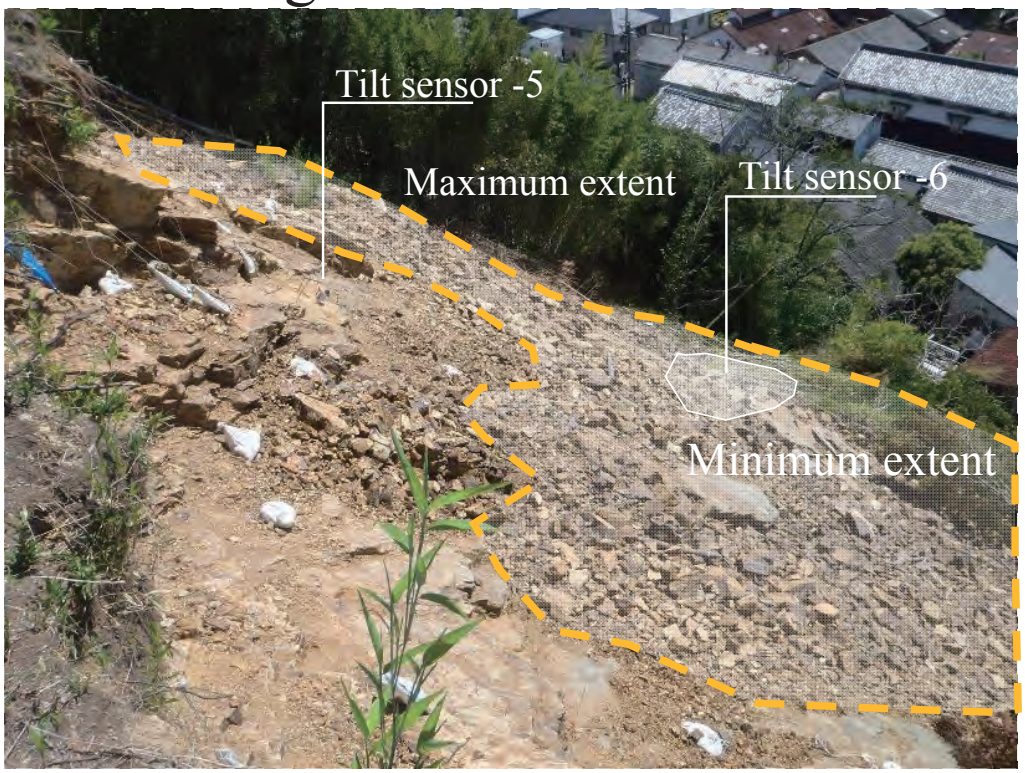
No failure

Rainfall record

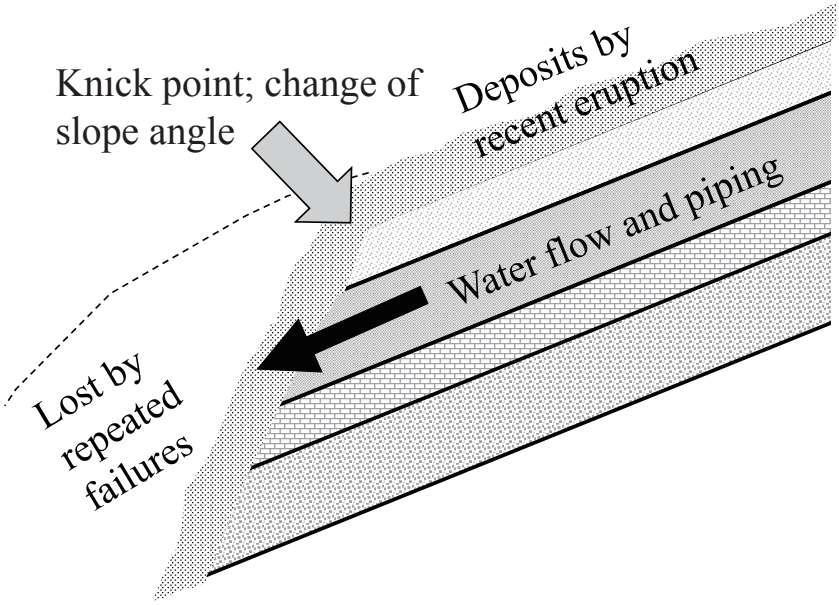




Monitoring of unstable stones



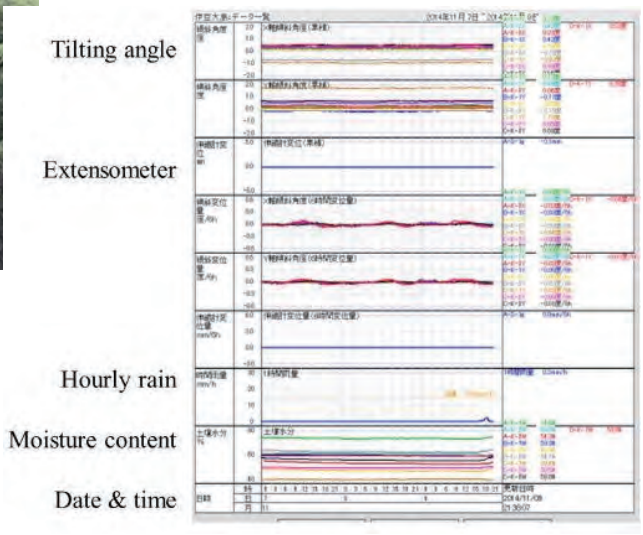
Basic mechanism of slope failure



Volcanic slope of Izu Oshima

Stratification makes the mechanism more complicated.

Izu Oshima again
Tilting angle was monitored in a very unstable slope but nothing happened.




Problems in early evacuation strategy

Increasing hazards of heavy rain and slope disasters

For Mitigation / Prevention,

Slope reinforcement (retaining walls, rock anchors) → good but expensive

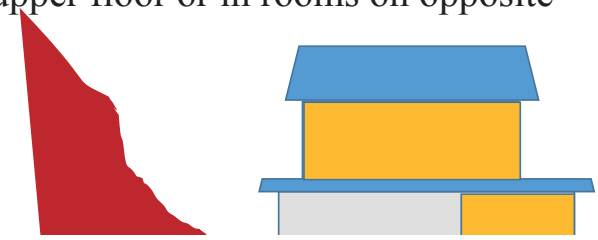
Relocation; moving to safer places; not preferred by people because they do not want to lose income

Brick production near Lahar (volcanic mud flow) stream; Philippines

Monitoring and early warning / evacuation; better than other choices but evacuation during mid-night heavy rain is dangerous.

Problems and possible solutions

Heavy rain in summer is likely in mid night: ground temperature is still high but air is cool at high altitude → rainfall.
Evacuation at midnight is not a safe idea.
Early evacuation (many hours before rain starts).
Think about staying on the upper floor or in rooms on opposite side of the mountain



Prediction of slope failure is not very accurate.
False positive (not predict failure but it occurs) has to be avoided.
False negative (predict failure but it does not happen) is inevitable.
After several false negatives, people will not trust warning.
Also, evacuation is tiresome; staying overnight in shelter?
Enjoyable evacuation.
Evacuation drill should be combined with music events, cooking school etc.

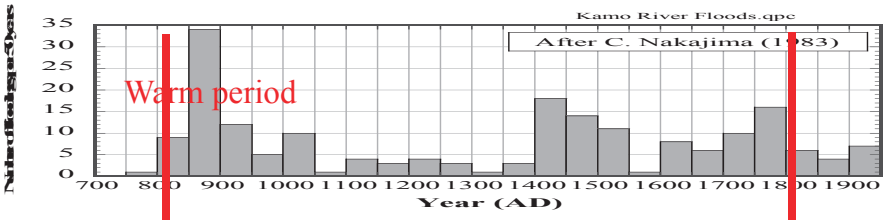
Global climate change (warming) is an urgent issue?

1. Long-term record of flooding and global temperature change was studied.
2. Flooding: Kamo River in Kyoto, 1000-year capital of Japan.
3. As the capital, Kyoto provides many written records of flood.
4. Temperature: from tree ring.

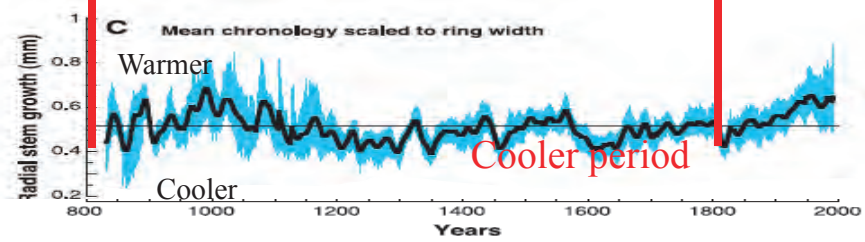
Kamo River in Kyoto

Frequency of flooding

Number of flooding as recorded by diaries (C. Nakajima, 1983)



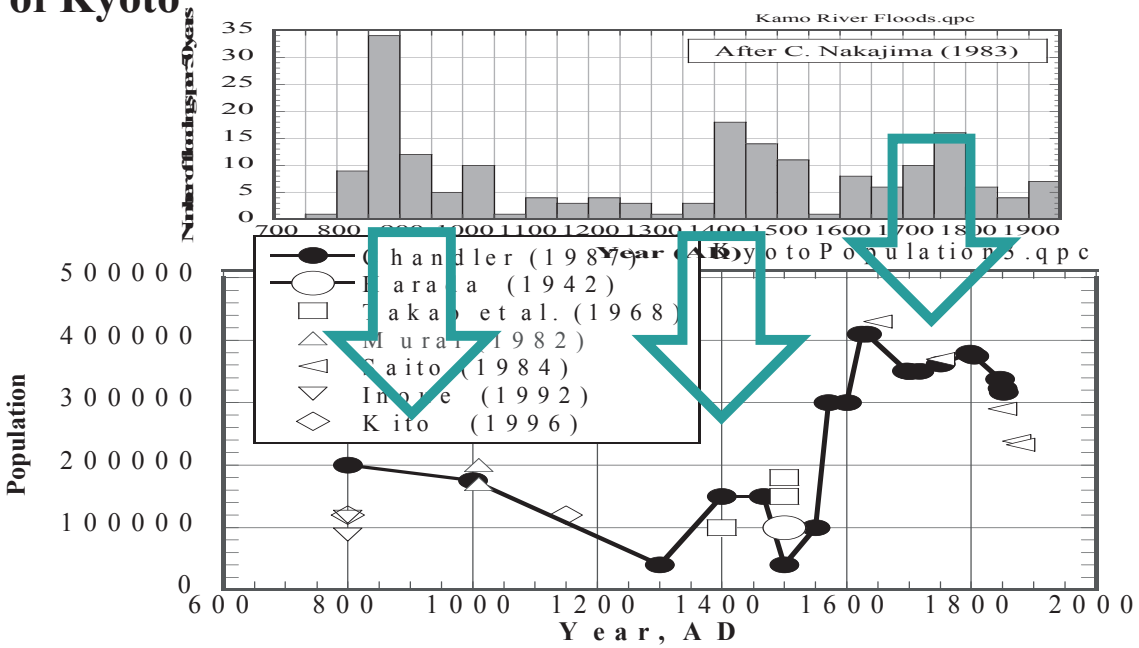
Temperature



Esper et al. (2002) Low-Frequency Signals in Long Tree-Ring Chronologies for Reconstructing Past Temperature Variability, Science, 295, pp.2250-2253.

No good correlation between flooding and long-term climate change.
Any other possibility?

Correlation between Kamo river flooding and population of Kyoto



Better correlation.
People cut down trees in mountains and increased the risk of flooding.

Consequence of **100-year tree planting (afforestation)**

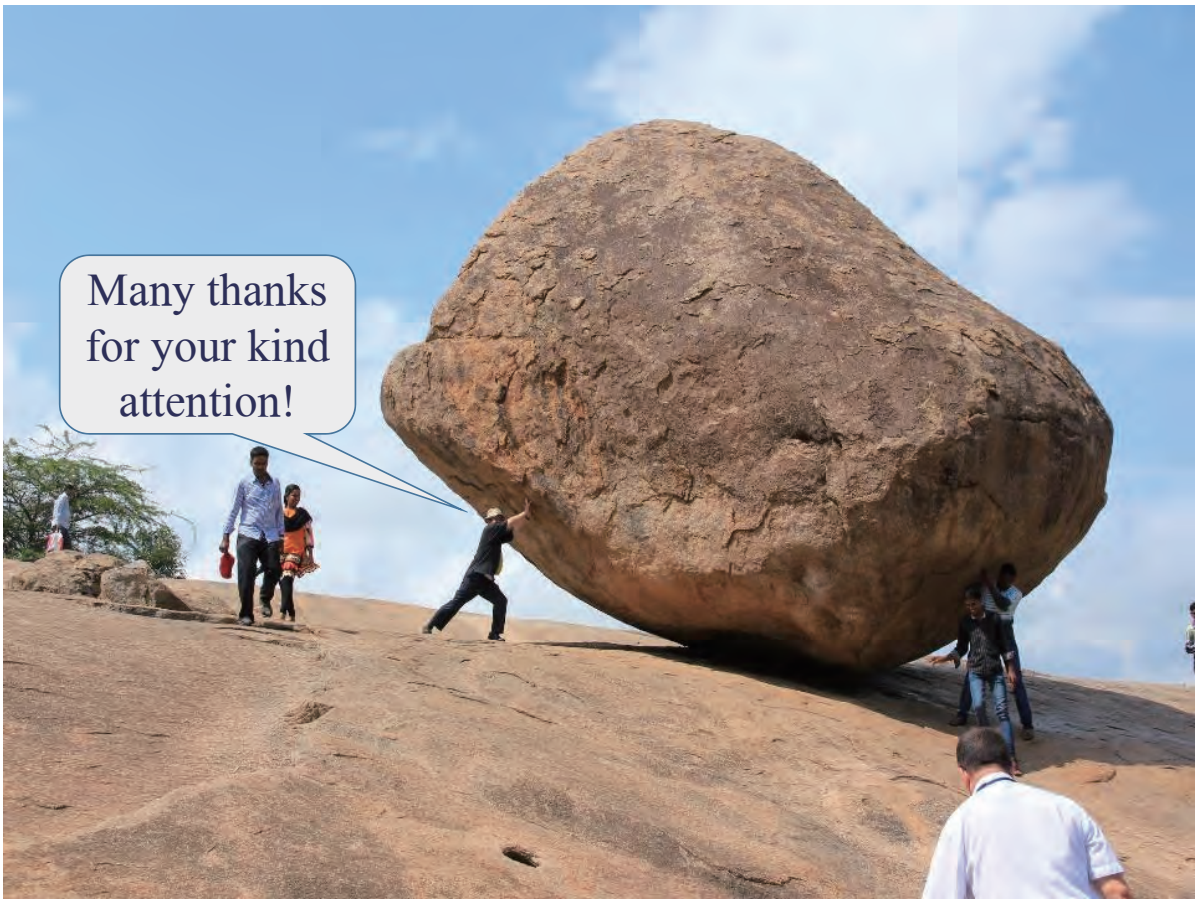
Disaster mitigation is not a topic of cost-benefit calculation.

Rokko Mountain

Tanakami Mountain

Conclusions

- MEMS tilting angle sensor has a reasonable cost and appropriate accuracy.
- Many sensors can be installed over an entire slope.
- Increased chance to detect the precursor (minor deformation) of ultimate failure.
- The displacement of a slope observed by tilting sensor and extensometer are equivalent.
- The tilting sensor responds earlier than the extensometer because of its installed location.
- Warning and evacuation when rate of tilting > 0.1 deg. / hour.
- Global warming may not soon affect slope disasters. Protection of forest is more important.



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