Prefailure deformation of unstable slope observed by tilt sensors
(2) – Case studies

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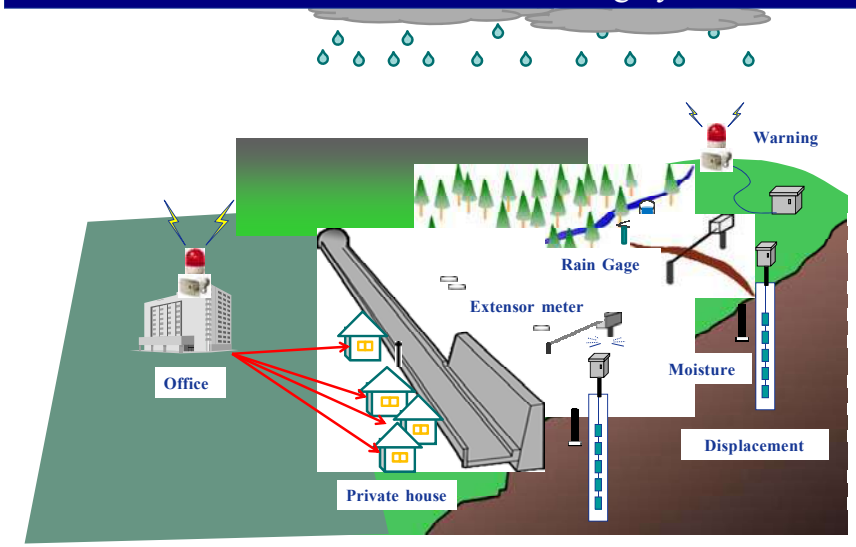
Contents

A traditional real time-monitoring-system



Recently, widely employed monitoring system. rainfall, displacement-> data is recorded->exceed critical value (warning is issued)

Some slope failure cases in Japan

Setup monitoring equipment=>Displacement rate increasing=>Slope could collapse=>Predicting collapse time=>Propagating take video=>Please see the collapse situation. The detail: 8th ISRM Congress, Sept. 25-29,1996,Tokyo,Japan, "Forecast Time and Analysis of Rupture Mechanism Using Video-tape Records for Failure of a Cut Slope"

- Traditional equipment such as extensor meter or multi-layer inclinometer is working effectively but,
  - High cost, still too expensive.
  - Difficult to install and maintenance.
  - Difficult to be used if don't know the exactly location of unstable soil mass.
  - Difficult to be used to zoning monitoring
- Developing a low cost sensor become necessary.

The Purpose of the Early Warning System development

-In Japan: 2573 landslides in 2005.
-More than 500,000 potential slopes
-Most of them are relatively small scale

Landslide site which hit residential houses in Kagoshima, Japan (Sep. 2005)

Low-cost and simple early warning system is needed.

To reach the purpose

- No cable
  =>Answer: Using wireless data transfer
- Careful selection of minimum measurement items
  =>Answer: Tilt angle and water contents
- Power saving, simple and low-cost measuring devices:
  =>Answer: Using MEMS technology

Usages of Low-cost and Simple Early Warning System

ADVANTAGES:

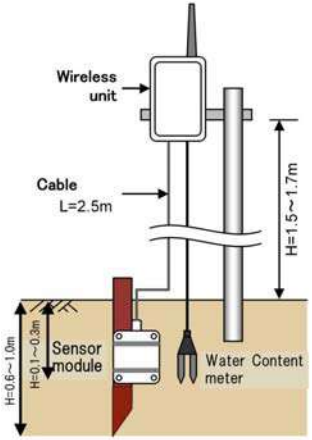
(1) The system can be handled by the residents in risk areas to protect themselves from disasters.

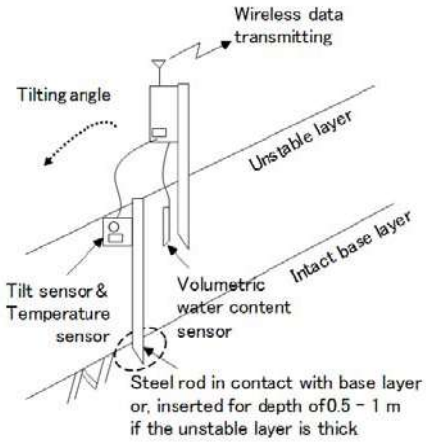
(2) The low-cost system is acceptable in many countries worldwide.

(3) Emergency deployment at disaster sites to prevent second accident. (Quick installation is possible as it is simple & wireless.)

(4) Other purposes of sensing for research and/or environmental monitoring are possible with low cost and easy installation, by attaching various kinds of sensors.

Wireless sensor unit with tilt and water content sensors on a slope

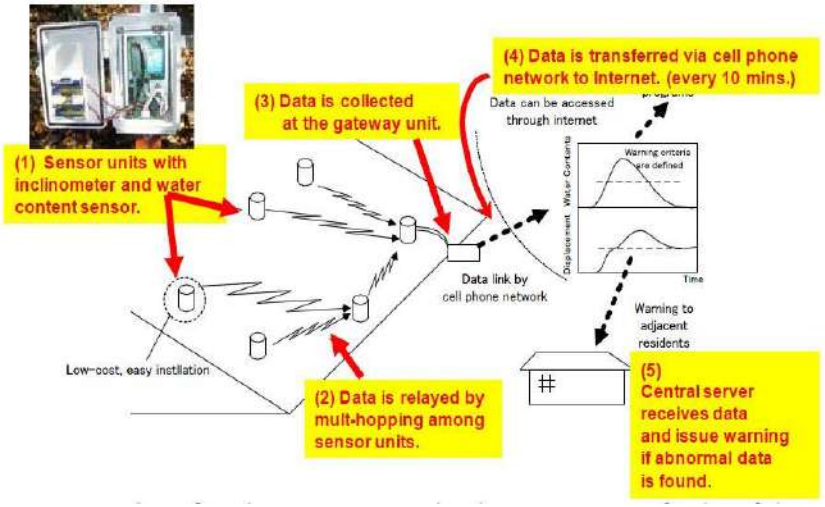




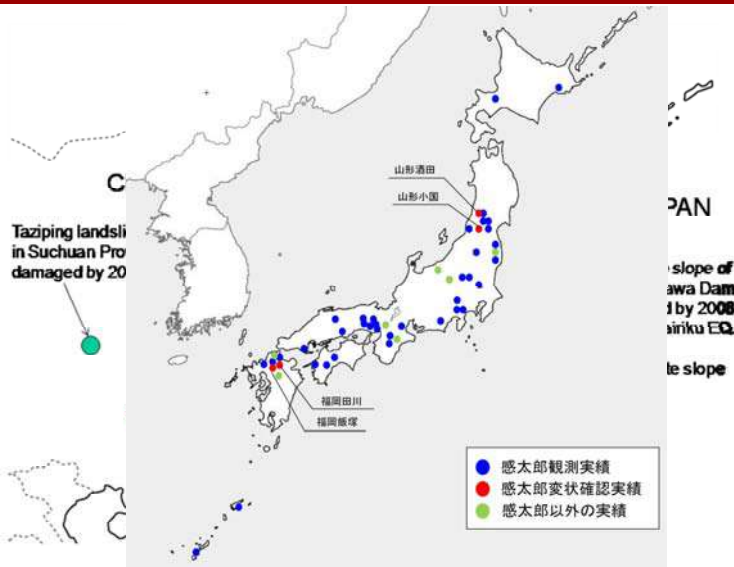
Wireless sensor unit with tilt and water content sensors on a slope

Outline of wireless monitoring and early warning system for slope failure

MOST RECENT PROTOTYPE (Japanese version)

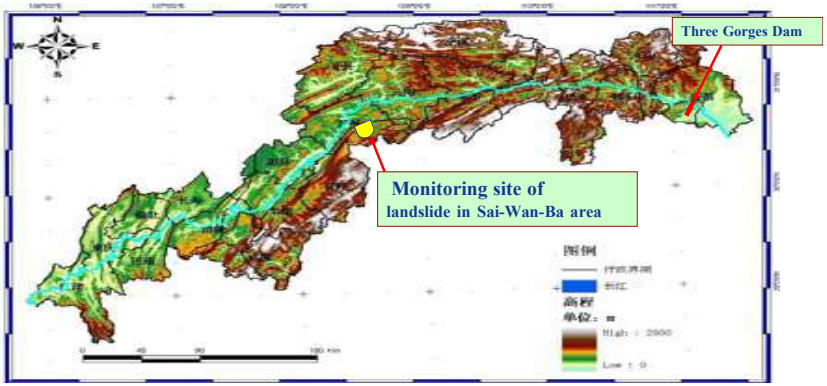


Test sites of developed monitoring system

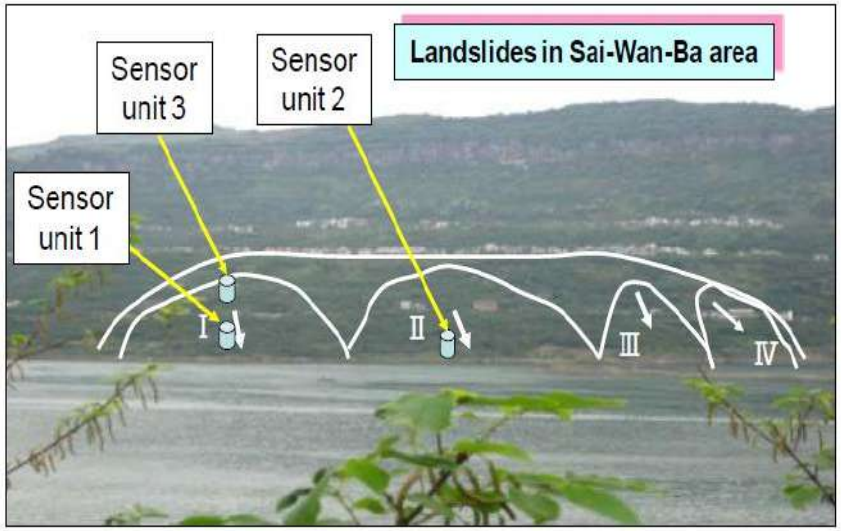


Monitoring case in Three Gorges Dam Landslide Area, China

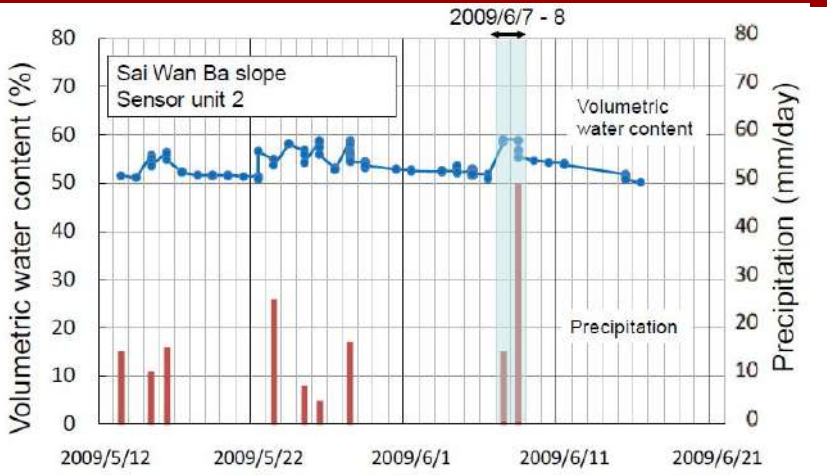
Submerged area of dam



Monitoring case in Three Gorges Dam Landslide Area

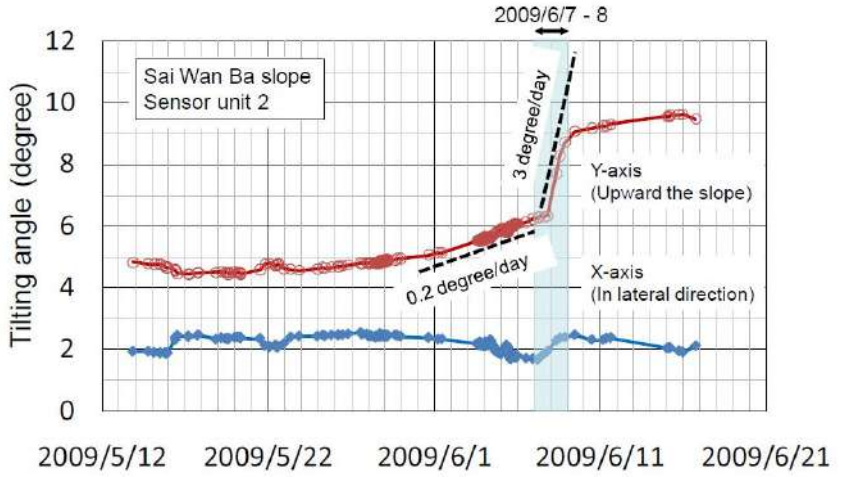


Monitoring case in Three Gorges Dam Landslide Area, China



Time history of volumetric water content transducer at Sensor unit 2, and records of rainfall intensity.

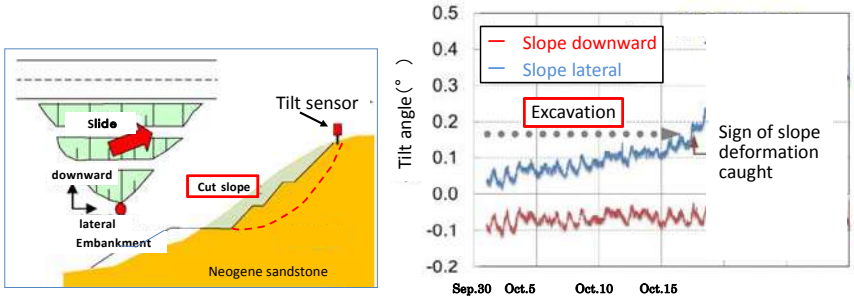
Monitoring case in Three Gorges Dam Landslide Area, China



Time histories of tilting angle obtained by Sensor unit 2.

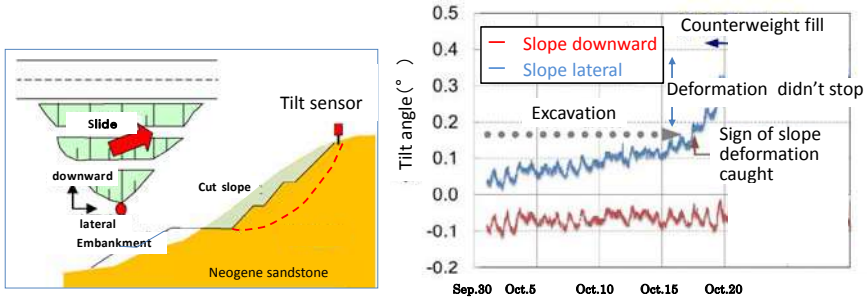
Above the sensor-2, New landslide formed on June 7, 2009.

Disaster prevention of the slope failure during national highway cutting slope construction in Tohoku district



Slope deformation sign was caught , and quick correspondence was done.

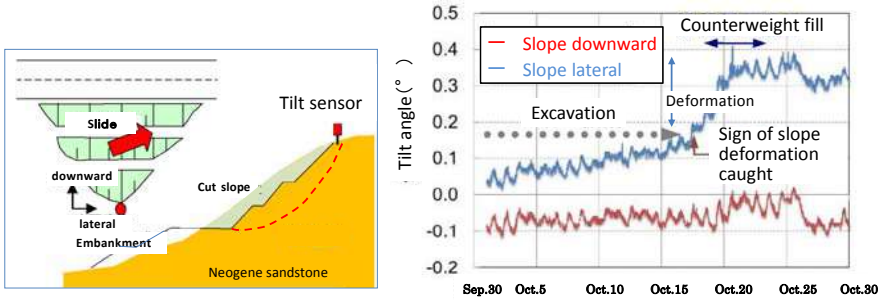
Disaster prevention of the slope failure during national highway cutting slope construction in Tohoku district



Slope deformation sign was caught , and the quick correspondence was done.
The deformation of slope didn't stop .

Sign of slope deformation → Notified to a field site office → Urgent Check → Counterweight fill

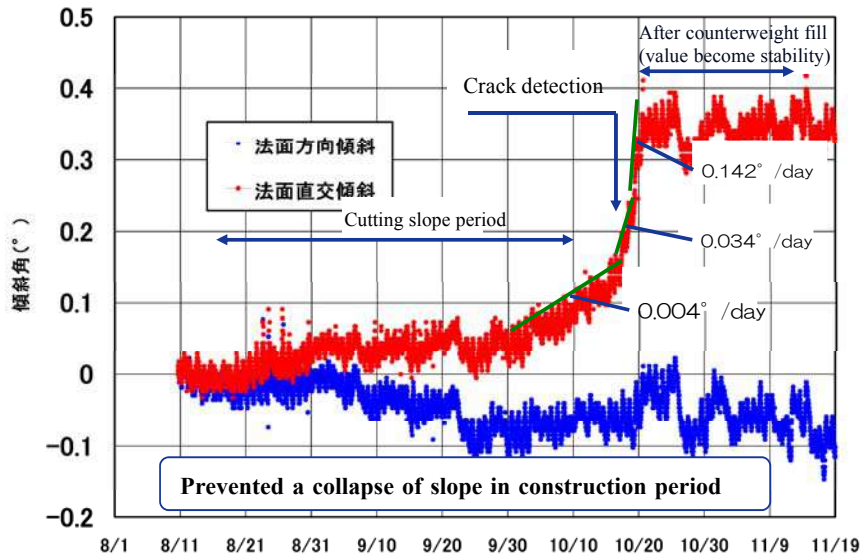
Disaster prevention of the slope failure during national highway cutting slope construction in Tohoku district.



Slope deformation sign was caught , and quick correspondence was done.
The deformation of slope didn't stop finally but slope failure prevented.

Sign of slope deformation → Notified to a field site office → Urgent Check → Counterweight fill → Slope failure prevented

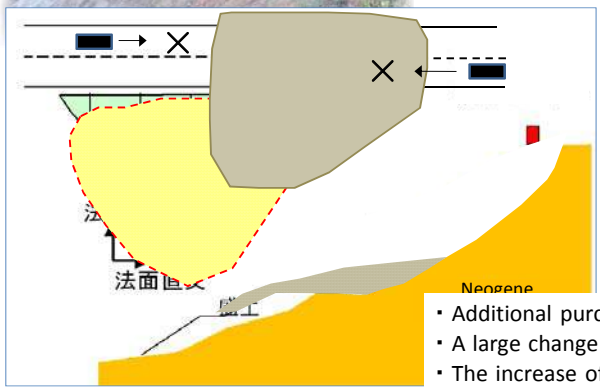
Case study of Safety monitoring of road cutting slope in Japan



If not do the monitored.

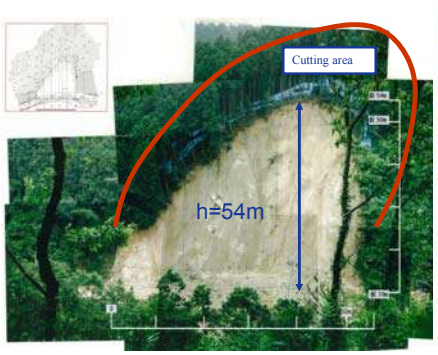
If not monitored ,
slope failure can not be avoided.

・The blockade of a common temporary road will affect another construction area.

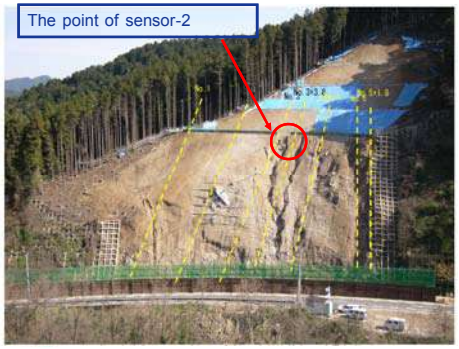


・Additional purchase of private land
・A large change of design
・The increase of construction cost

Case study of safety monitoring of road slope in Kyushu, Japan

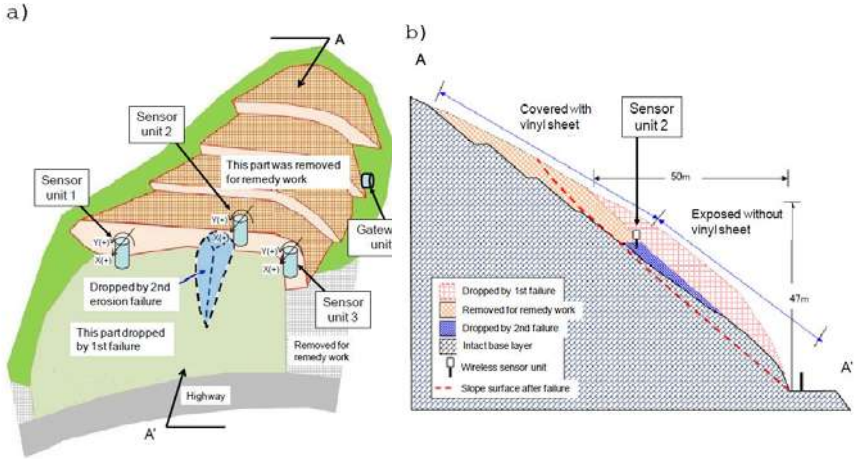


The slope situation after failure happened
（high weathered granite）



Slope erosion by another rainfall

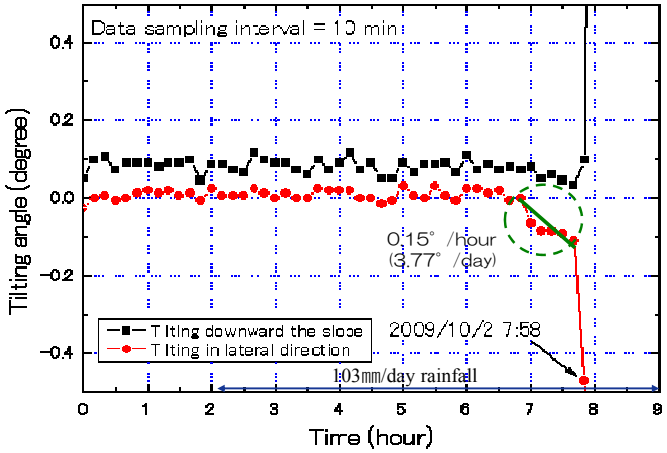
Sensor units deployed on a slope failure site along road of Kyushu



a) Sketch of failed slope along road and arrangement of deployed sensor unit; and b) cross-section of the slope including the second failure part.

Case study of Safety monitoring of road slope in Kyushu, Japan

Tilting angle on a slope site along road just before second failure



Sensor units deployed on monitoring of a possible slope failure site along national road in Kyushu recently

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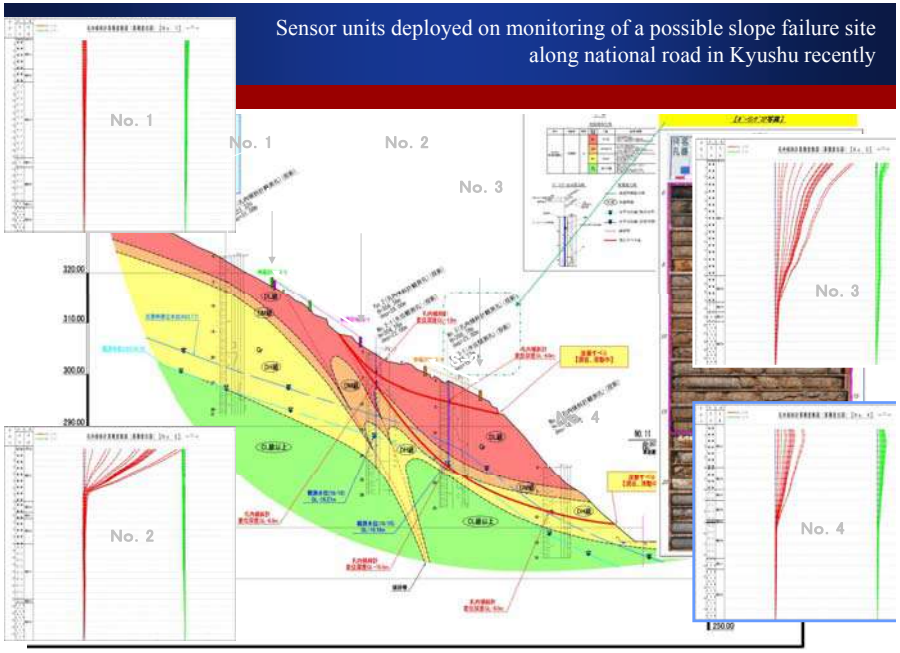
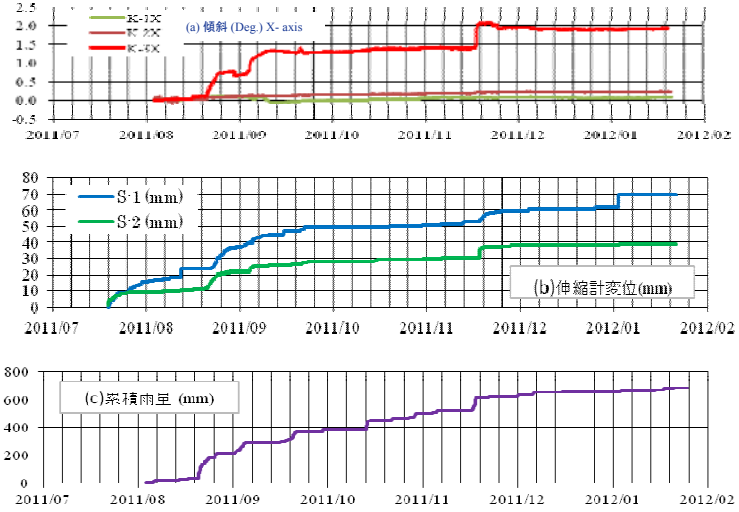
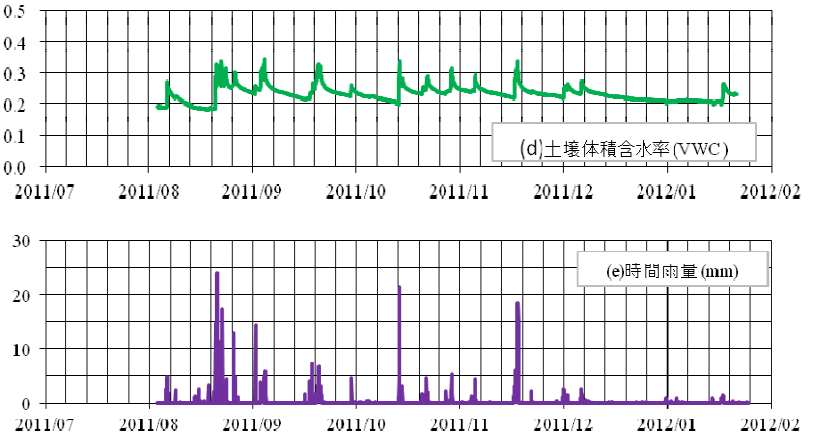


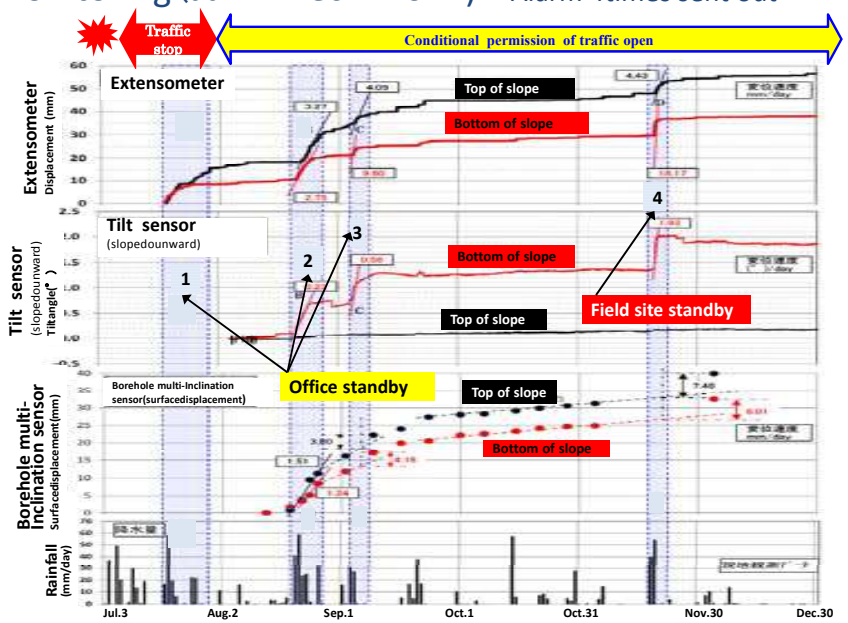
Sensor units deployed on monitoring of a possible slope failure site along national road in Kyushu recently



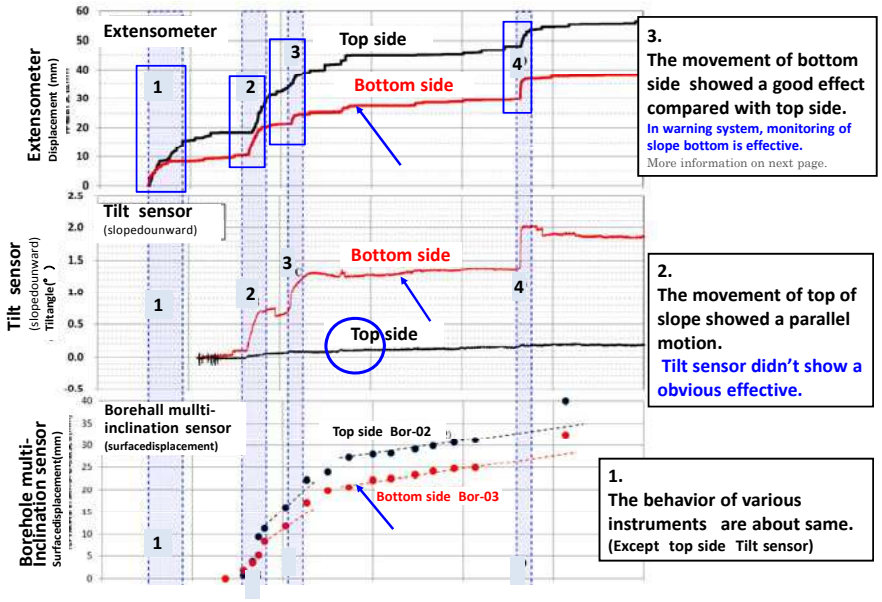
Sensor units deployed on monitoring of a possible slope failure site along national road in Kyushu recently



Monitoring（Jul.～Dec.in2011）　Alarm 4times sent out



Monitoring（Jul.～Dec.in2011）



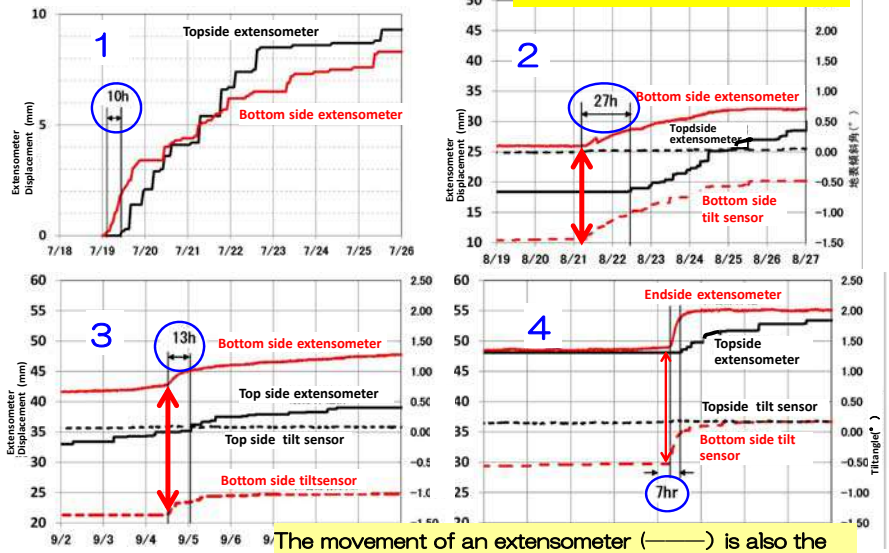
3.
The movement of bottom side showed a good effect compared with top side.
In warning system, monitoring of slope bottom is effective.
More information on next page.

2.
The movement of top of slope showed a parallel motion.
Tilt sensor didn't show a obvious effective.

1.
The behavior of various instruments are about same.
(Except top side Tilt sensor)

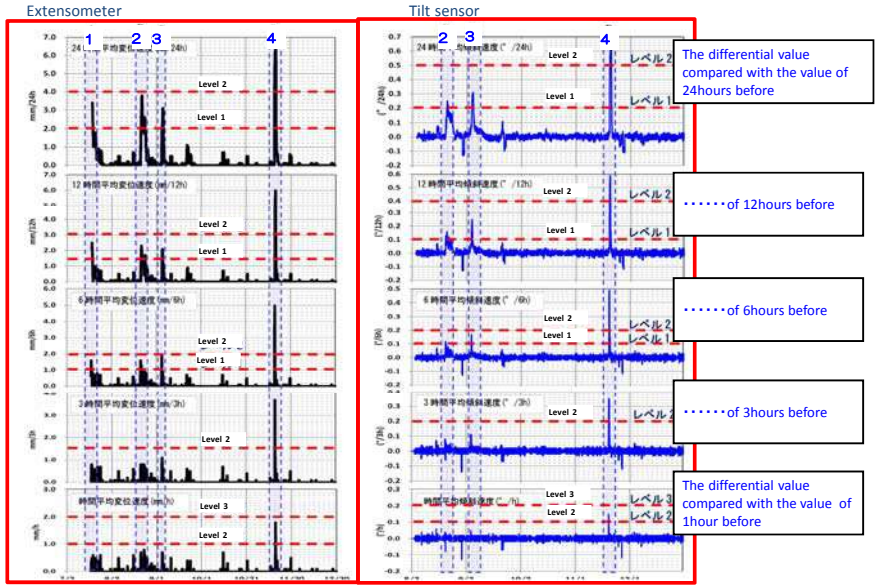
The timelag of change

Deformation at bottom of slope starts earlier than top of slope.



The movement of an extensometer (———) is also the same with tilt sensor(·····) at bottom of slope.

It is easier to understand the situation differential value than cumulative value.



The differential value compared with the value of 24hours before

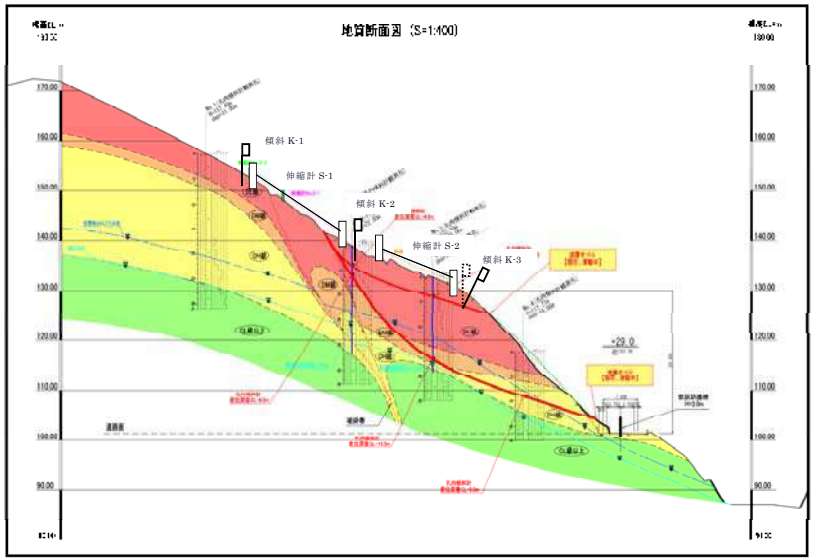
·····of 12hours before

·····of 6hours before

·····of 3hours before

The differential value compared with the value of 1hour before

Sensor units deployed on monitoring of a possible slope failure site along national road in Kyushu recently



The threshold value was readjusted by field information

Highway Committee (extensometer)

Watch action level	threshold value	threshold value (conversion)
Be careful	5mm over /10days	0.12mm over /6h
Considering of correspondence	5～50mm /5days	0.24～2.4mm /6h
Warning	10～100mm /1day	2.4～24mm /6h
Traffic stop	100mm over /1day	24mm over /6h

Apply to this case (extensometer)

	Watch action level	threshold value /6hours	threshold value /1hour	Remarks
0	Usual (alarm release)	Under 0.2m/h during 3 hours		50% of level 1
1	Office-standby	3mm	0.5mm	50% of level 2
2	Field-site standby	6mm	1mm	50% of level 3
3	Traffic Stop	12mm	2mm	50% of highway committee value

readjust

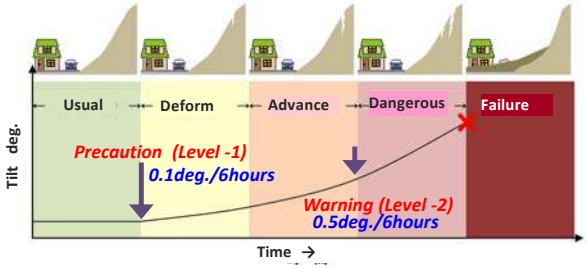
compare

Level		Extensometer mm/24h	mm/6h	mm/h
0	Usual (alarm release)	Under 0.2m/h during 3 hours		
1	Office-standby	2.0～	1.0～	
2	Field-site standby	4.0～	2.0～	1.0～
3	Traffic stop	10.0～	6.0～	2.0～

Level		Tilt sensor °/24h	°/6h	°/h
0	Usual (alarm release)	Under 0.05° /h during 3 hours		
1	Office-standby	0.2～	0.1～	
2	Field-site standby	0.5～	0.2～	0.1～
3	Traffic Stop	1.0～	0.5～	0.2

Conclusion

1. Tilt sensor can be used easily to early warning monitoring system.
   - Tilt sensor behavior is in a good agreement with extensometer behavior except topside of deformed slope.
   - Low cost　- Easy installation
2. Decision of the threshold value of early warning by tilt sensor is important. An example of threshold was shown at case 3.
3. But, it is very difficult to decide the threshold of slope failure because it depends on slope failure pattern such as landslide , shallow failure , erosion failure ,debris flow, deep- seated failure , rock fall and so on. More future task will be required to decide.
4. The professional engineering judgment for slope instability is the most important.



In Collaboration with the JSPS Core to Core program Is Presenting the Workshop on Monitoring Early Warning and Mitigation of Landslides

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Thank you for your attention.