1st International FLAC/DEM Symposium on Numerical Modeling
27 August 2008, Minneapolis, MN USA

Analysis of a seismically induced highway embankment failure during the 2007 Noto earthquake

P. Kitiyodom, **A. Murata**, Y. Sasa
E. Shimamoto, T. Matsumoto, M. Kitaura

Kanazawa University
Kanazawa, Japan

Outline of Talk

1. Introduction and outline the Damages of the 2007 Noto Earthquake
2. Field Observation on the Embankment Damages
3. Analysis of a Road Embankment Failure using FLAC3D
4. Conclusion

Introduction

What is the factor of big destruction?

Scale of earthquake at these sites?

Ground water table?

Geology, topography?

Shape of embankment?

Quality of operation?

etc.

The retrofitting method?

Geo-textile?

Compaction?

Foundation improvement?

Drained material?

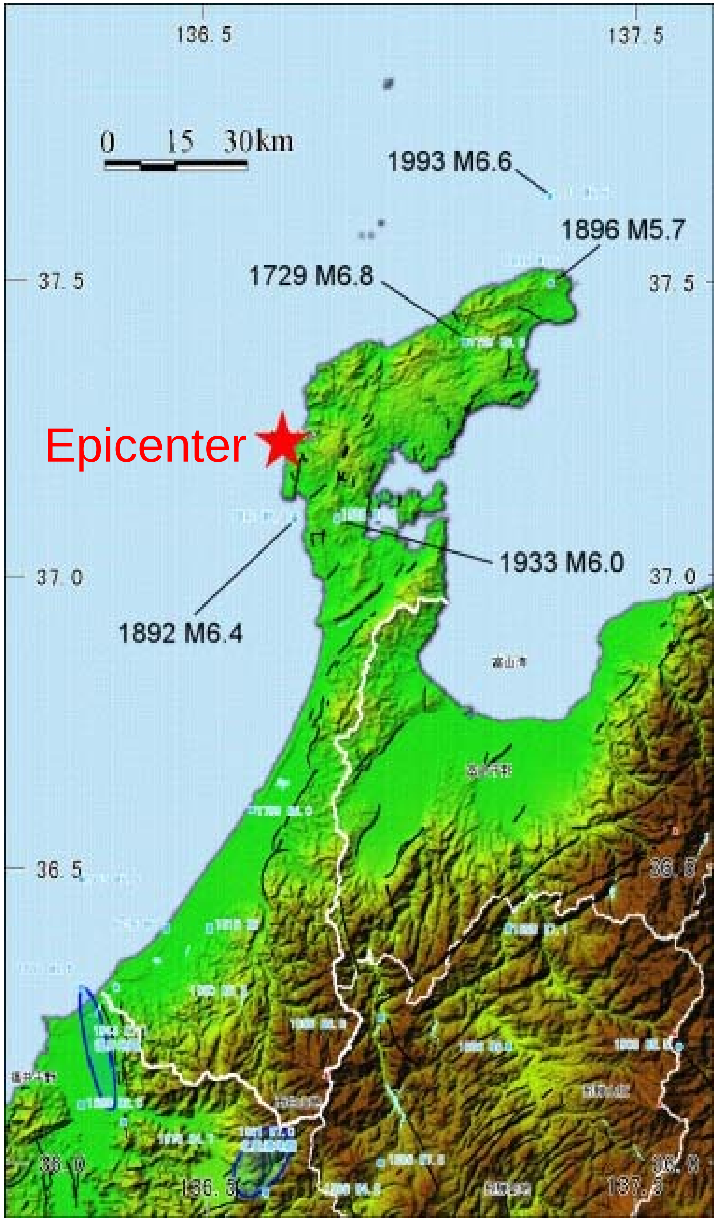
etc.

A situation of those days is irreproducible!

↓

Analytical examination is performed using FLAC3D.

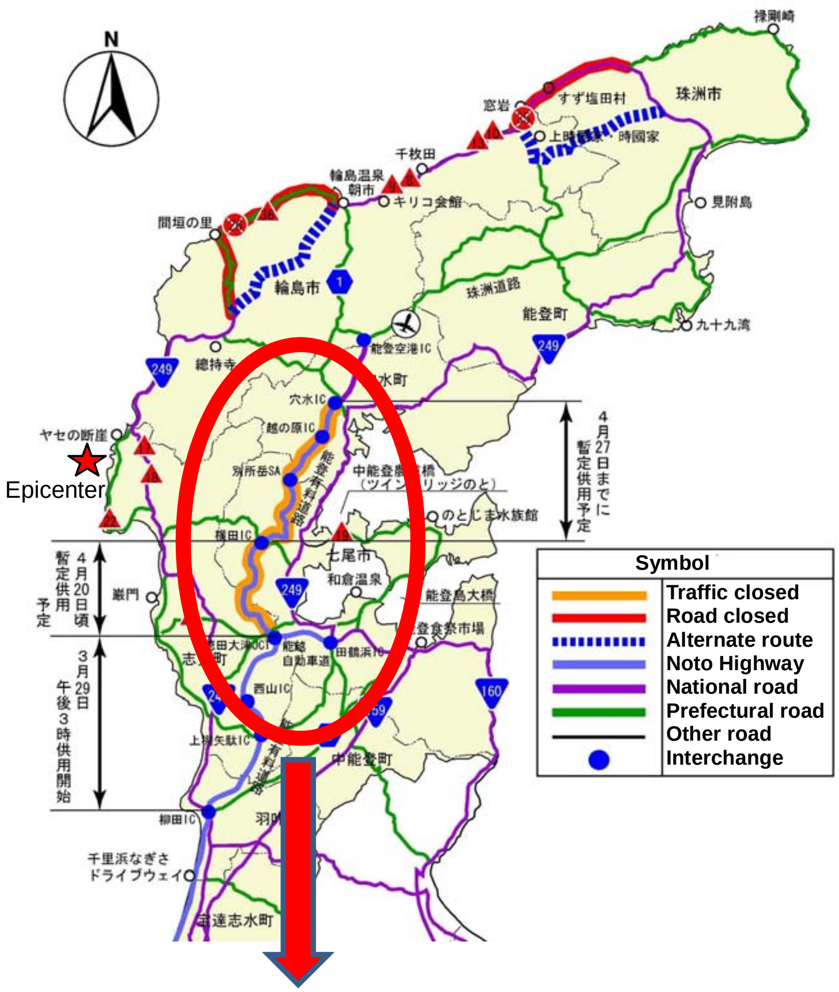
The 2007 Noto Earthquake



Occurrence 9:42am, 25th March, 2007
Magnitude = 6.9 (the Richter scale)
Maximum seismic intensity = 6+ (the JMA scale)
Dead: 1
Injuries: 2,224
Completely collapsed houses: 649
Partly collapsed houses: 25,940

Damages to Engineering Structures and Buildings

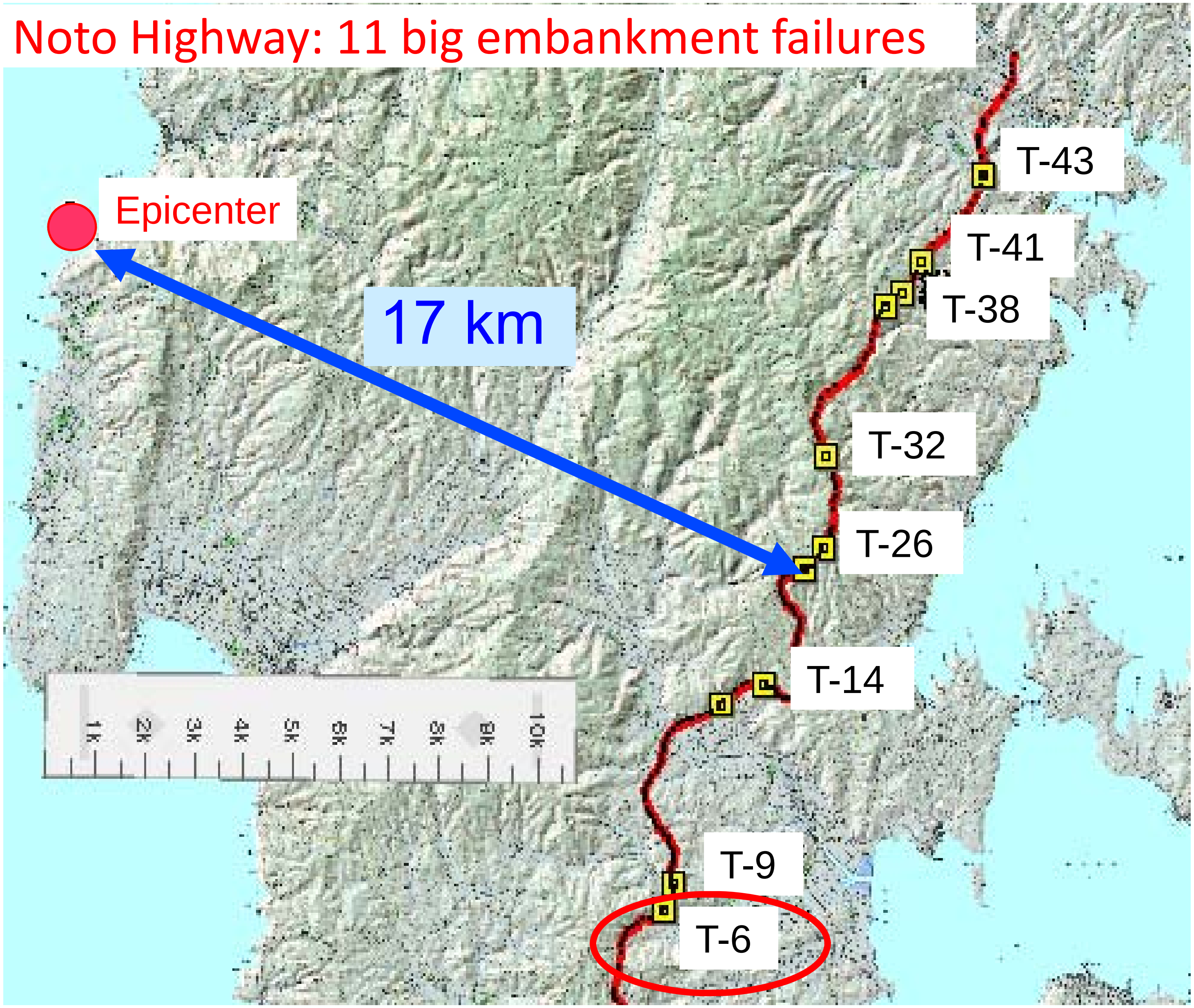
Highway Road Embankments Failures



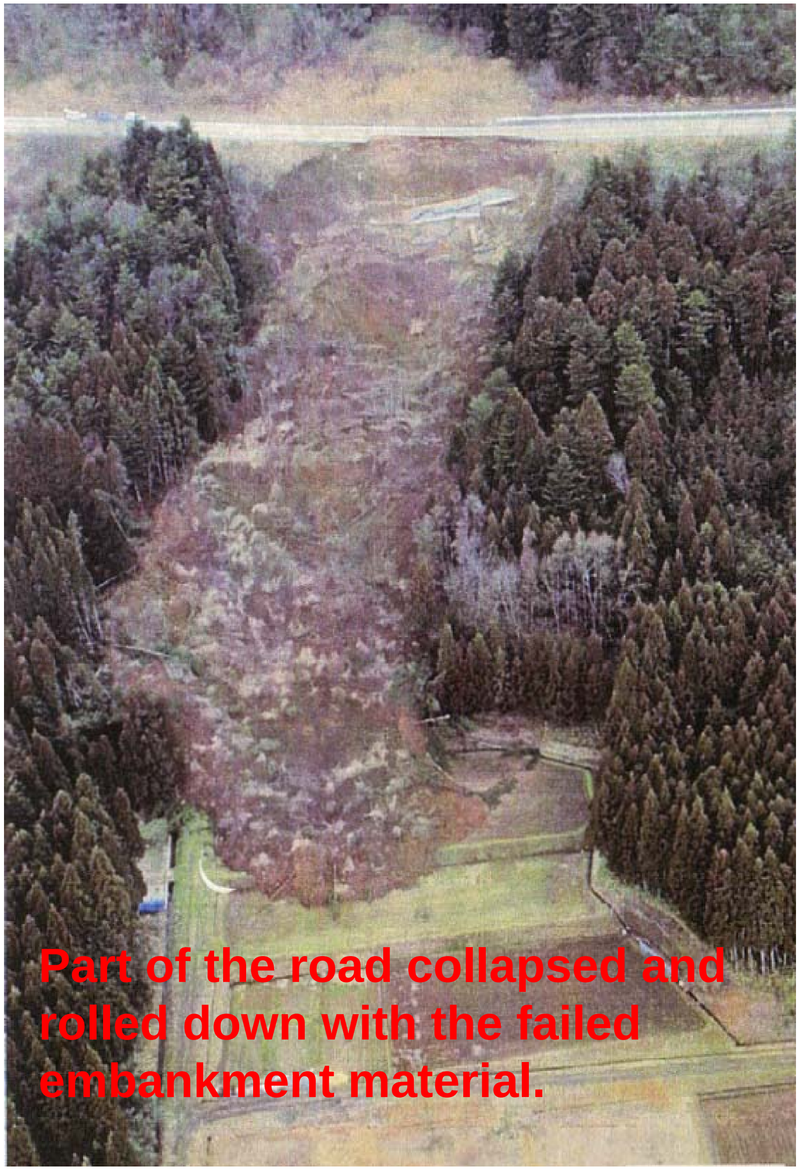
This highway connects main cities in the Noto Peninsula to Kanazawa city. This highway was an important route for recovery, it needed to be made to restore promptly.

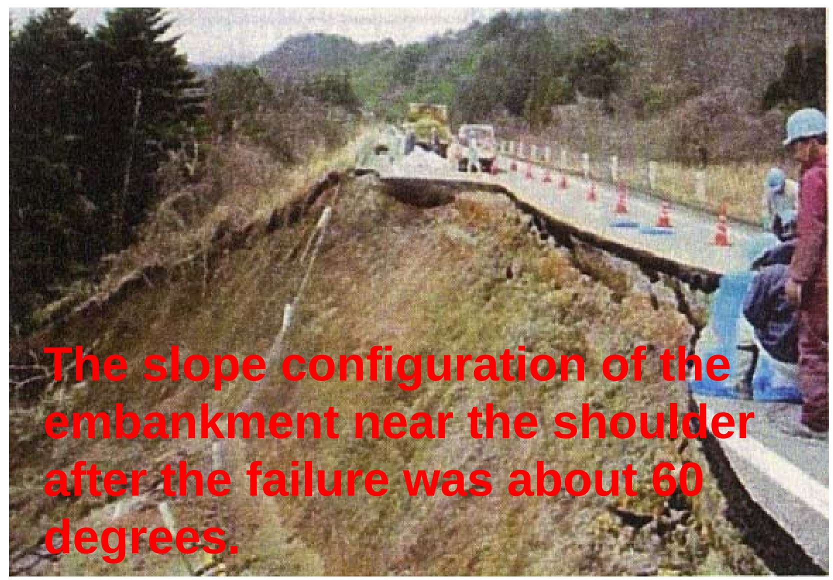
Noto Highway: 11 big embankment failures

Highway Road Embankments Failures



Highway Road Embankments Failures





Embankment failure at site T6

Highway Road Embankments Failures

Damage (2007.3.25)

After Emergency Restoration (2007.8.10)

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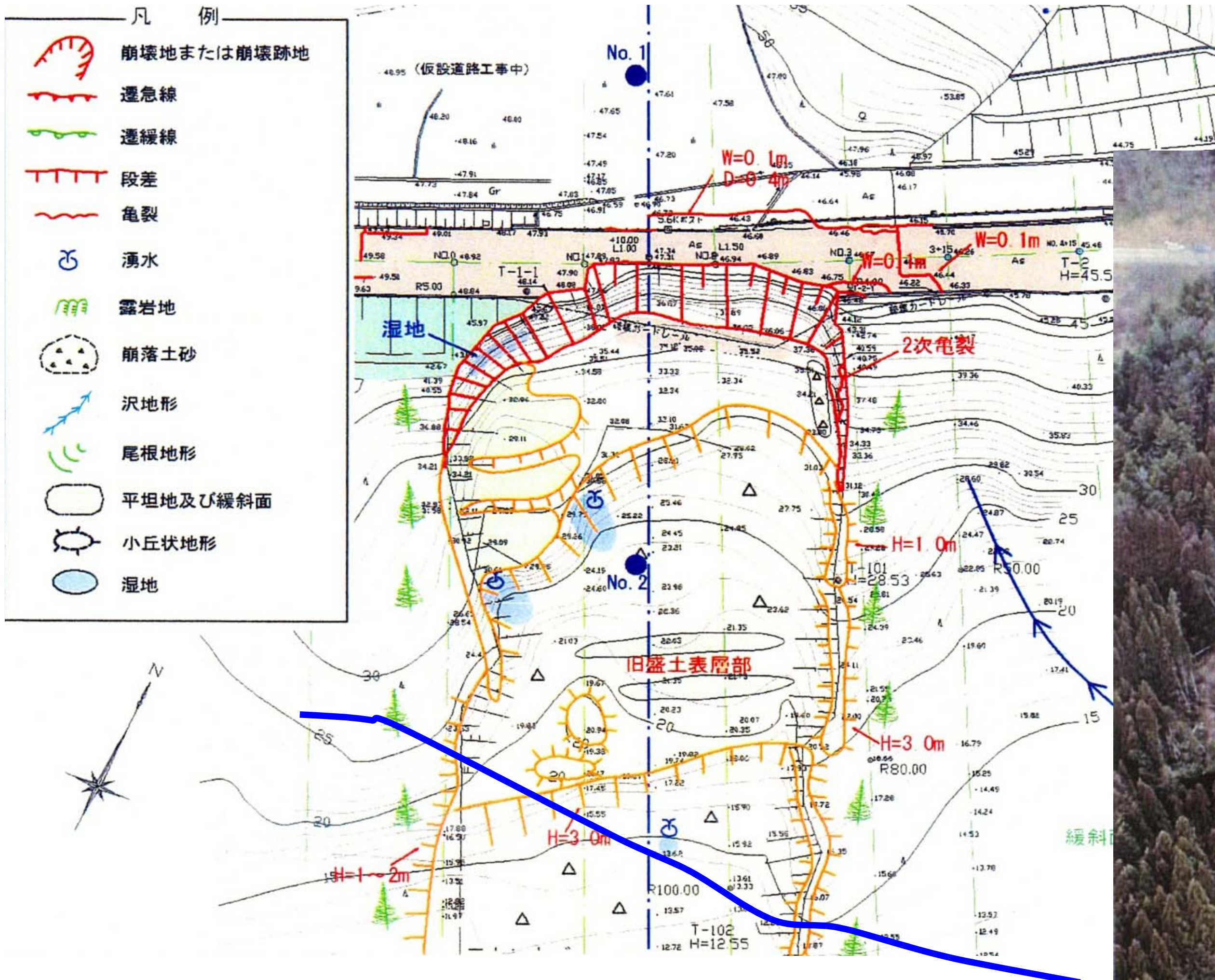
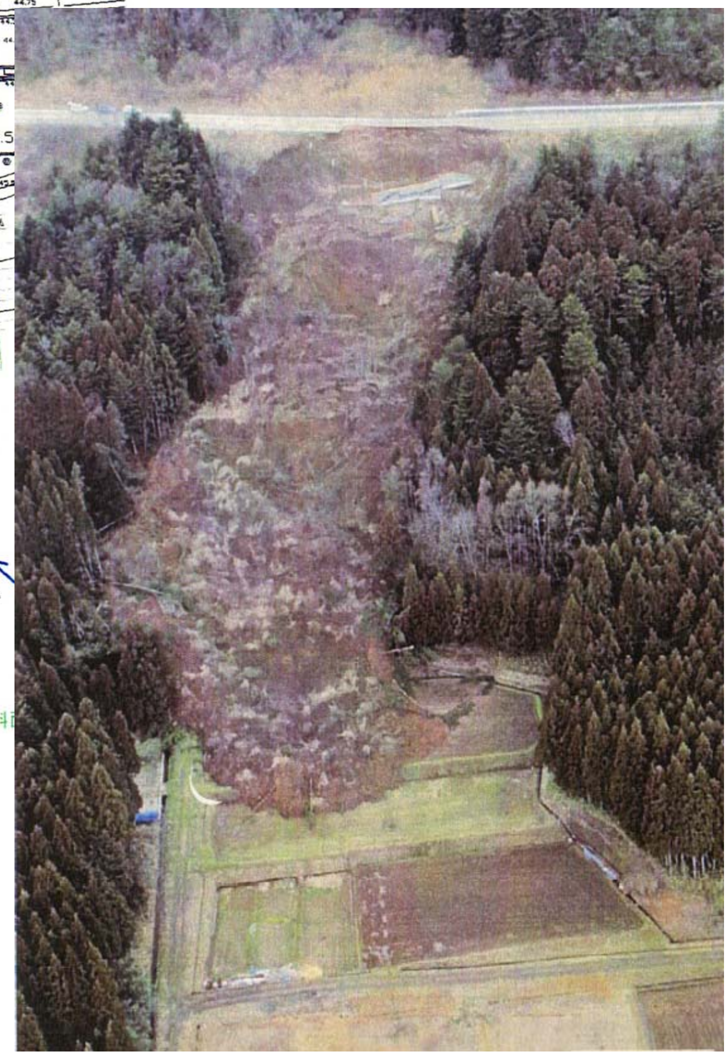
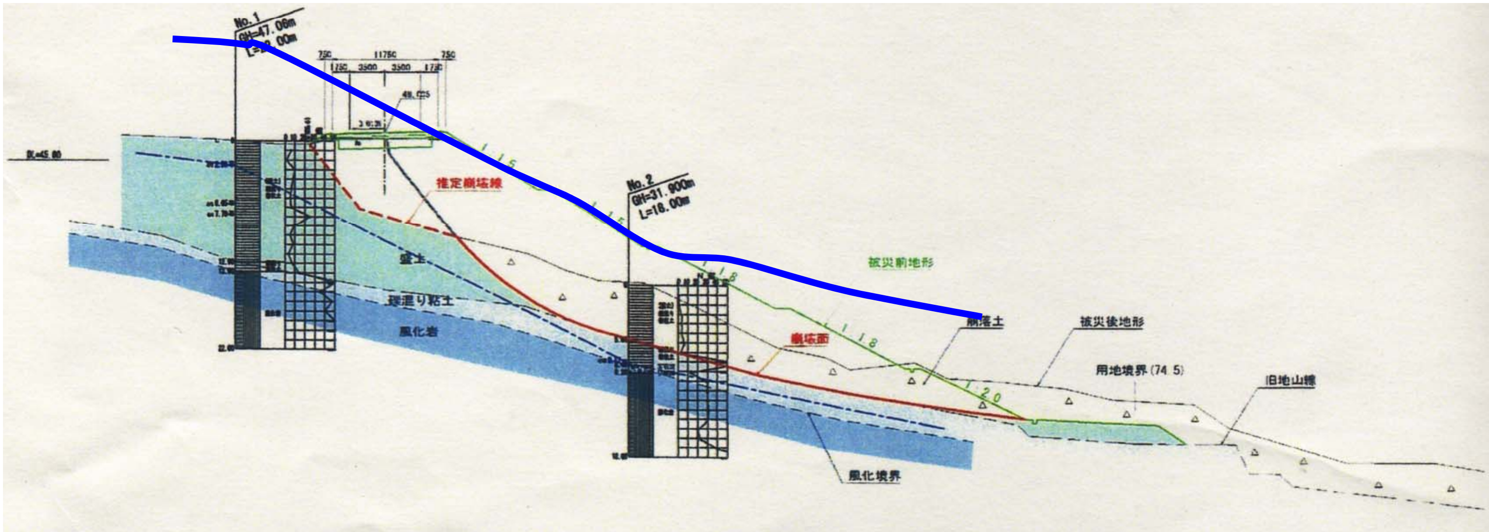
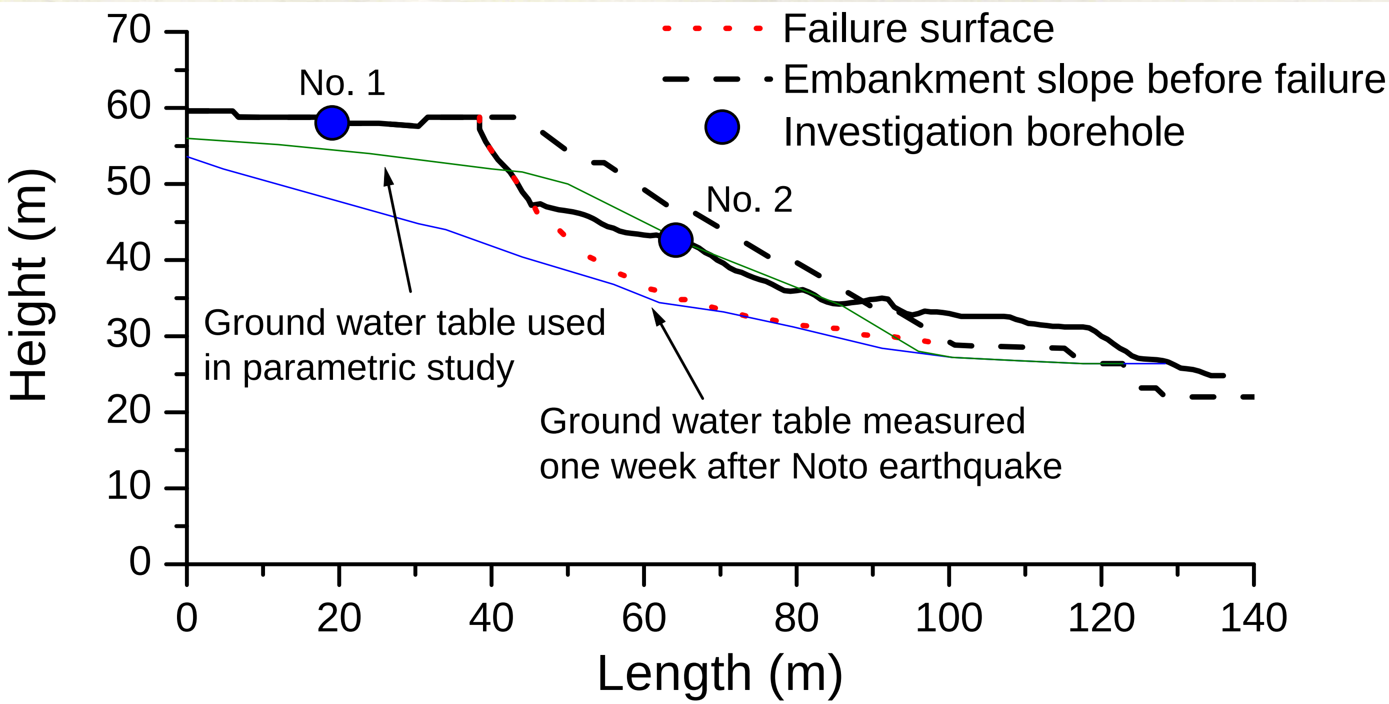
Field Mapping of the Embankment damage at Site T6



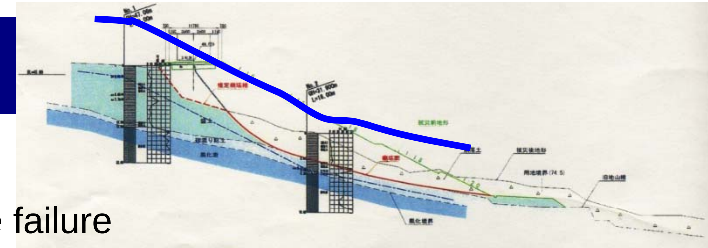


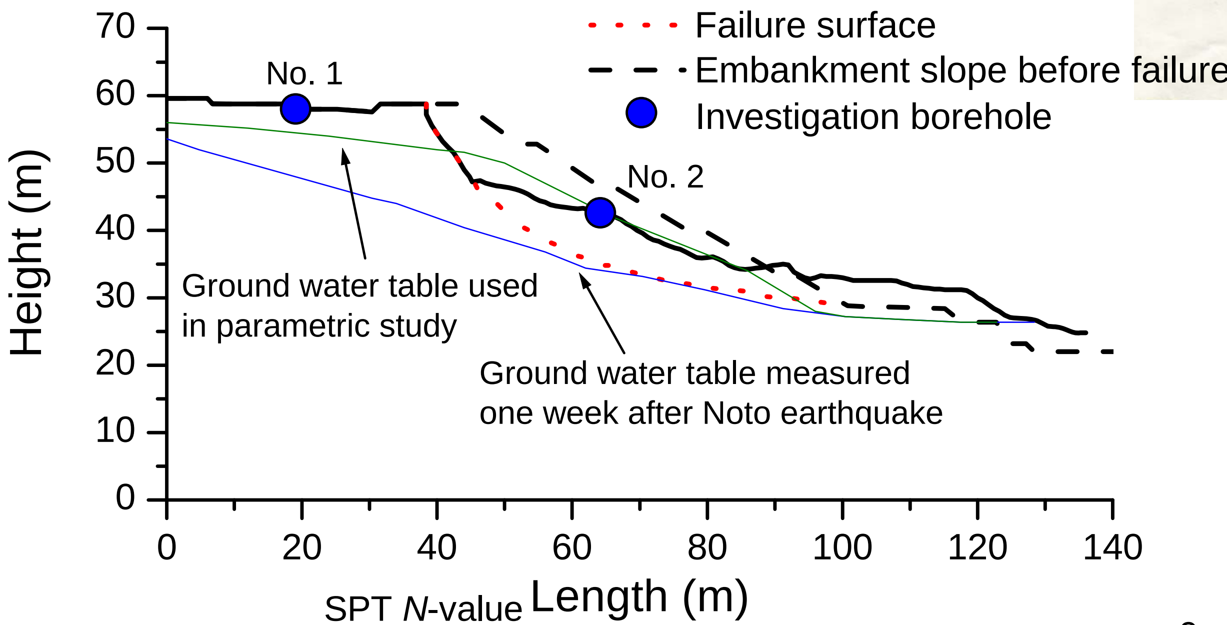
Cross Section of Embankment damage at Site T6

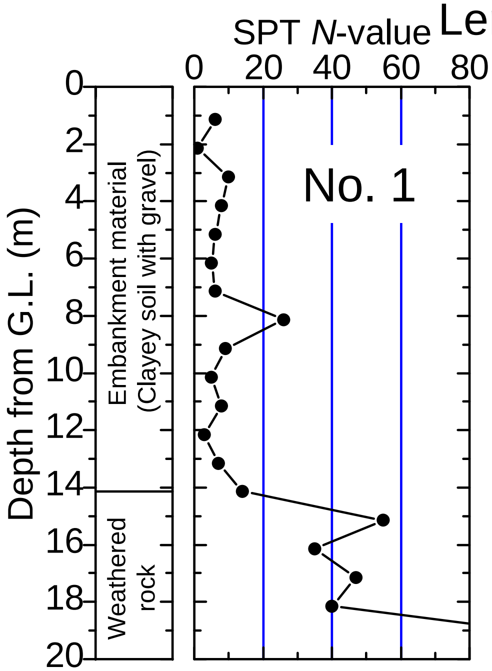


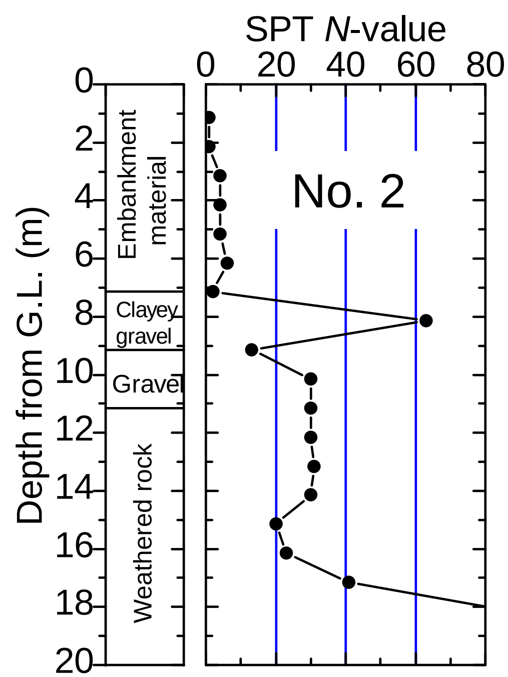


Cross Section of Embankment at Site T6

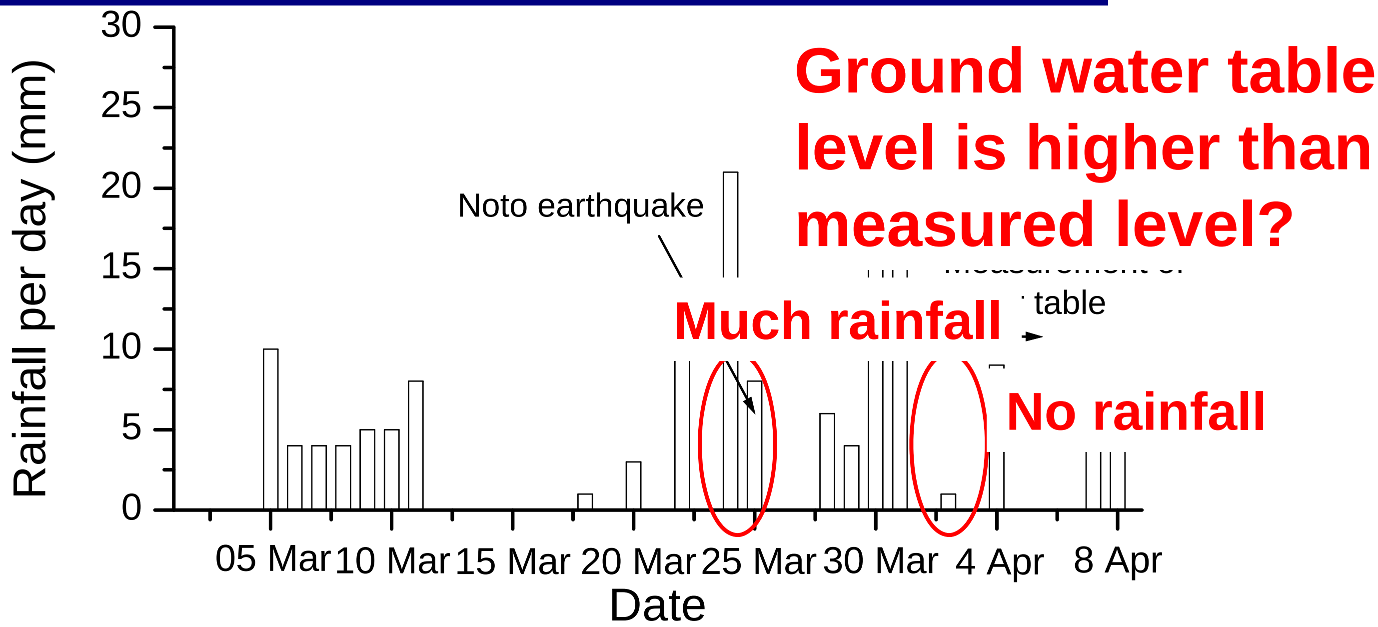


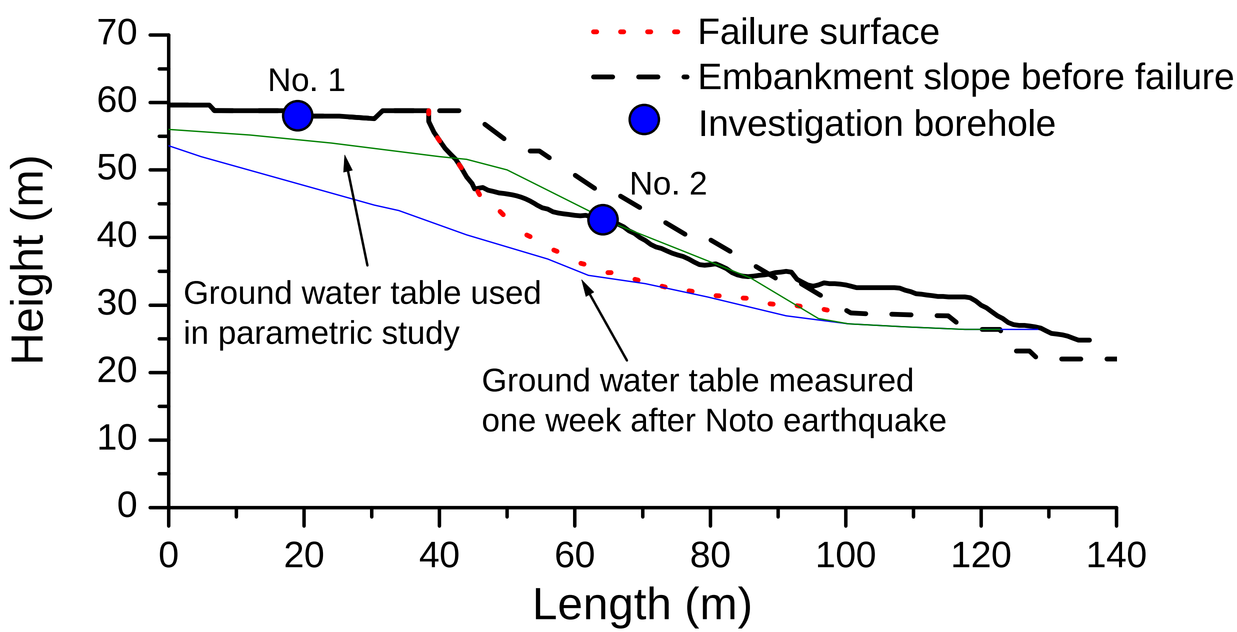






Rainfall at Noto Peninsula Area



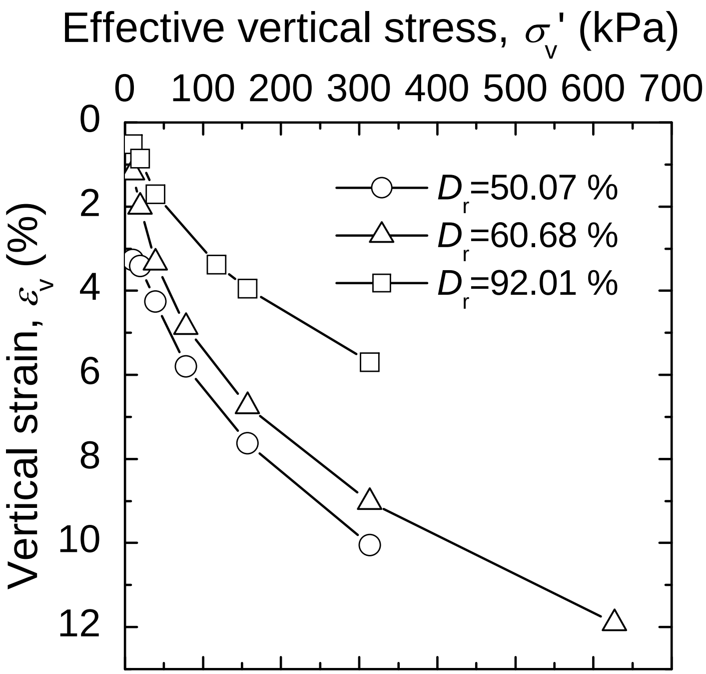


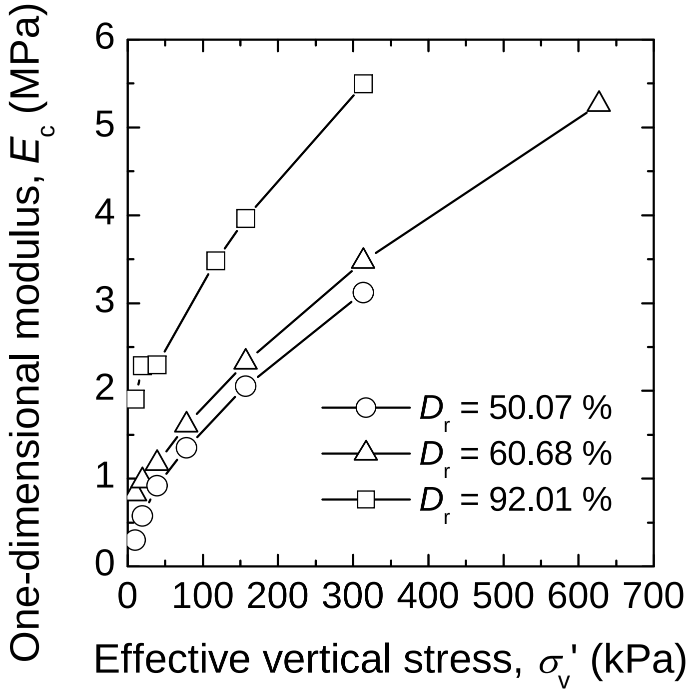
Properties of Soil at the Failure Surface of T6

The soil samples were collected from the site using thin wall steel pipe with a diameter of 75 mm.

Property	Value
Dry density at site (ton/m^3)	1.09
Wet density at site (ton/m^3)	1.54
Water content at site (%)	41.45
Maximum dry density (ton/m^3)	1.25
Minimum dry density (ton/m^3)	0.91
Density of soil particle (ton/m^3)	0.75

Results of one-dimensional compression tests



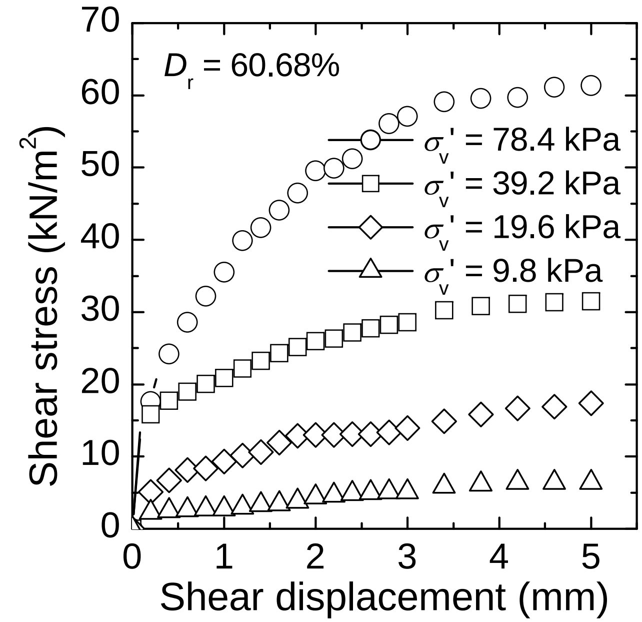


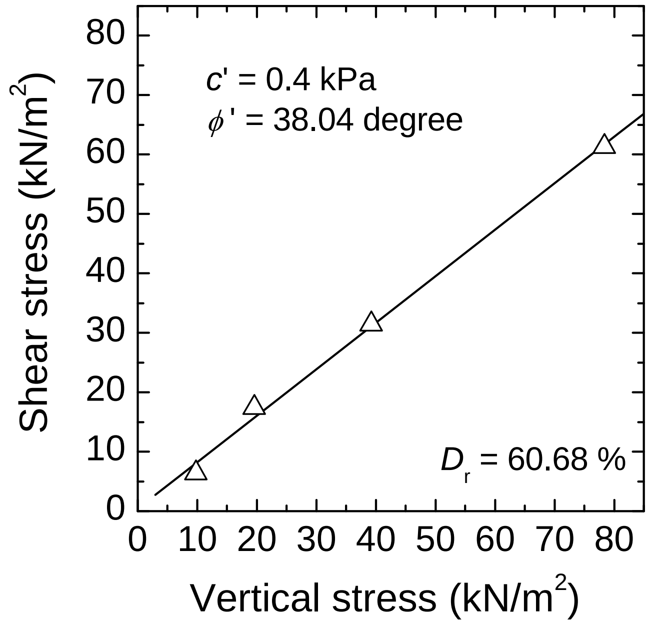
Effective vertical stress vs vertical strain

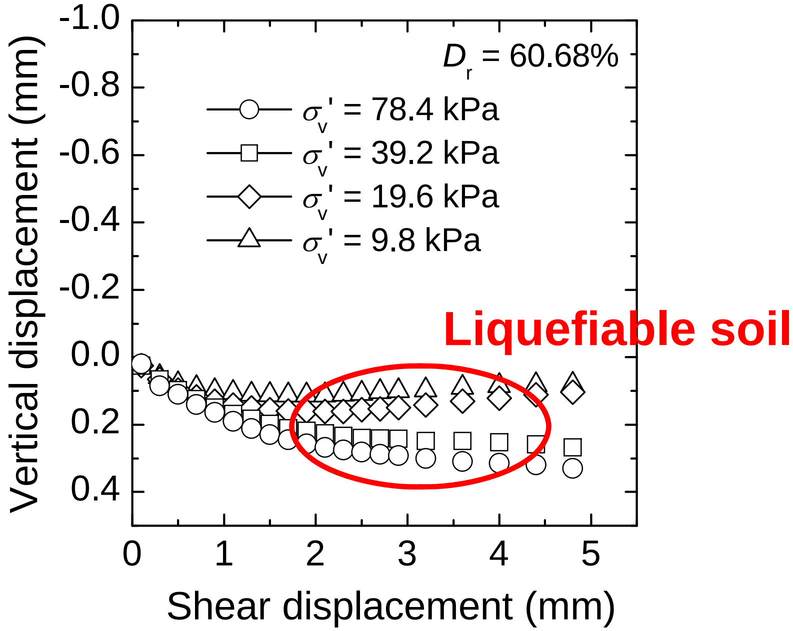
Effective vertical stress vs 1-D modulus

The results of the tests on the dried soil sample with the relative density of 60% were used in the analysis.

Results of direct shear tests







Ductile material

$c' = 0.4$ kPa

$\phi' = 38.04°$

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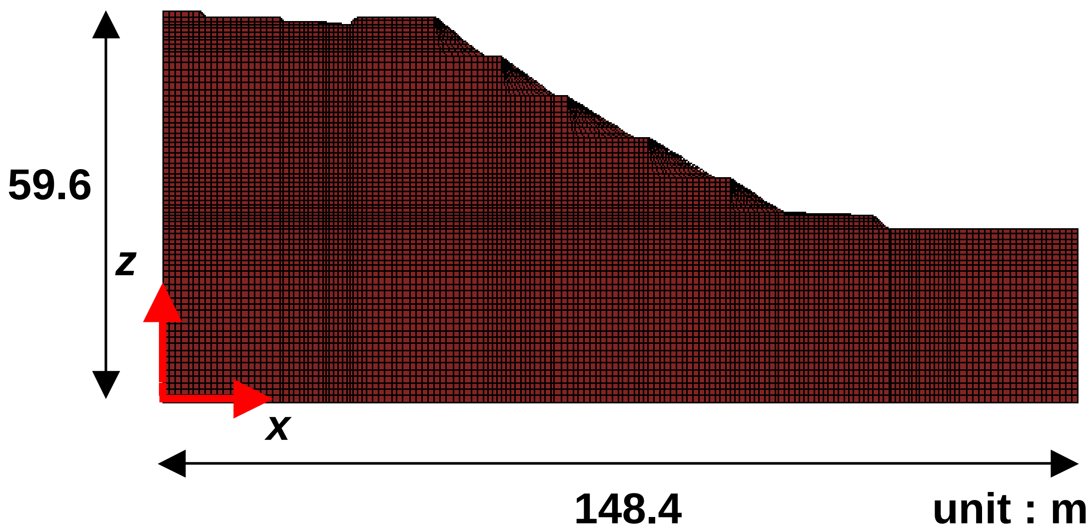
Parameter of a Road Embankment Failure using FLAC3D



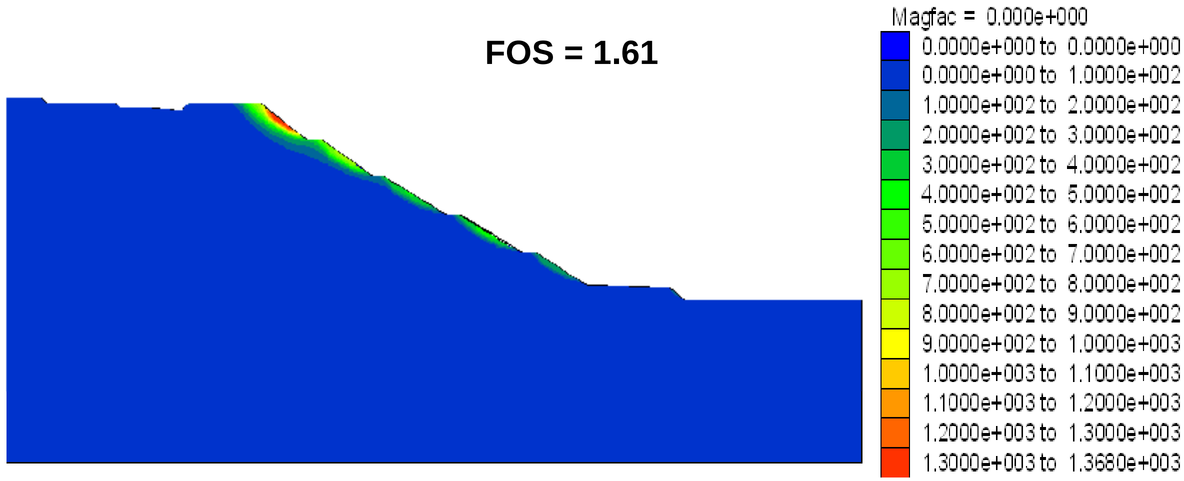
Unit length in *y*-direction

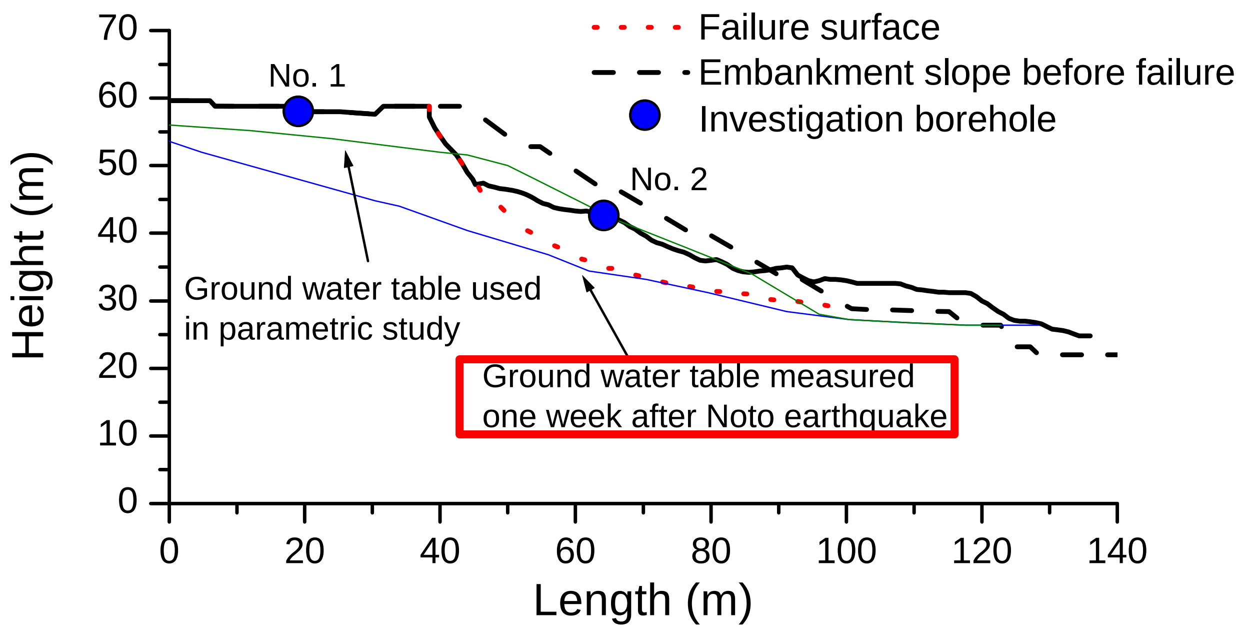
Plane strain condition

Mohr-Coulomb material

Property	Value
Soil density (ton/m^3)	1.54
Saturated soil density (ton/m^3)	1.69
Bulk modulus (kPa)	1457
Shear modulus (kPa)	627
Friction angle (degree)	38.04
Cohesion (kPa)	0.4

Results –ground water table after failure

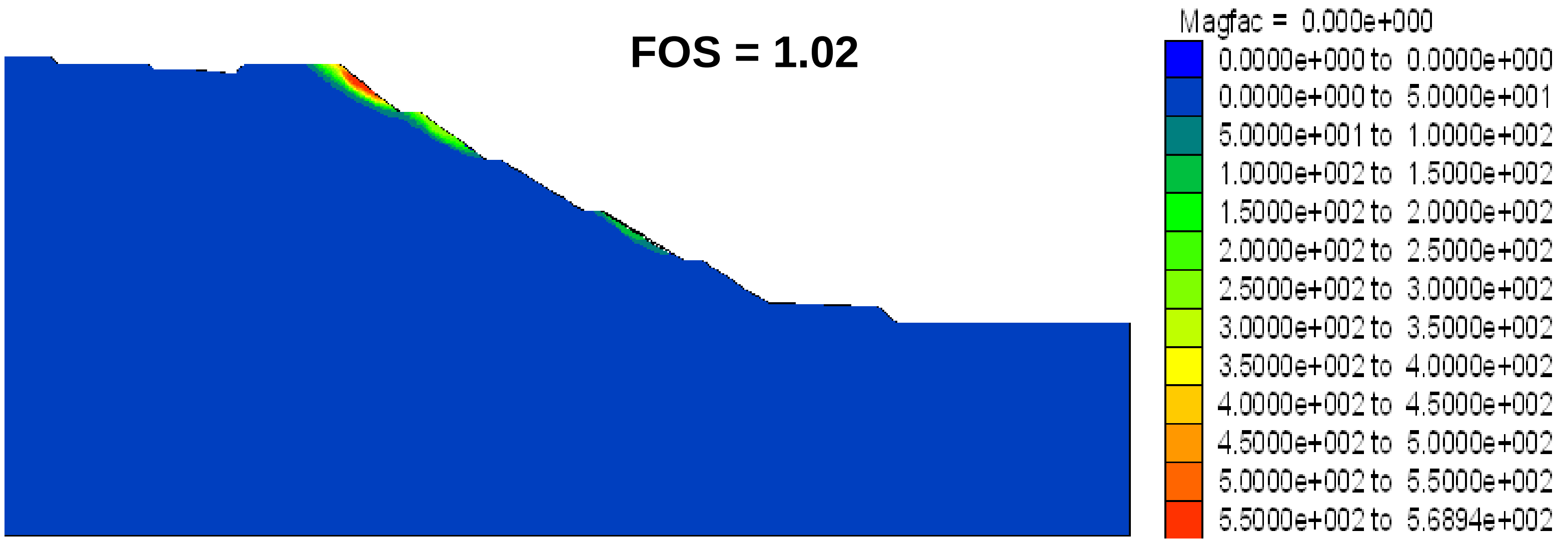




Safe?

But…

Parametric Study Results (include equivalent static hor. acc.)

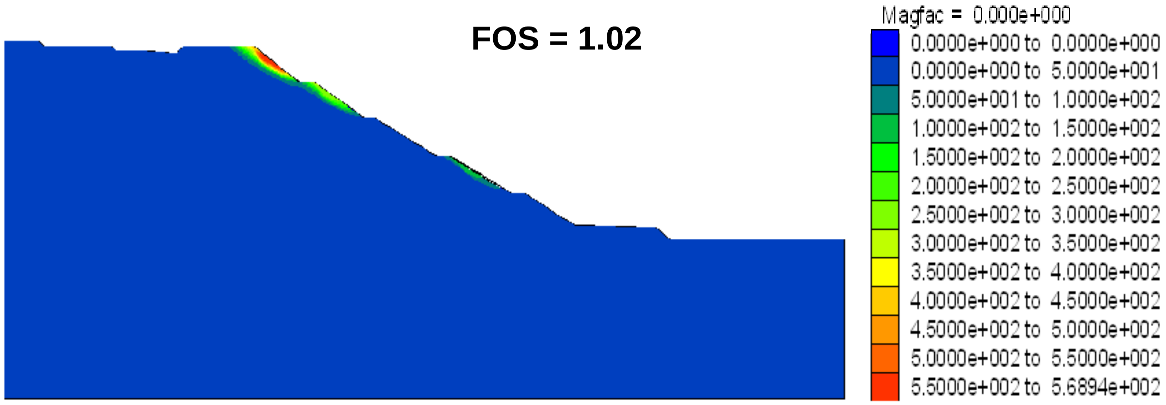


Equivalent static
horizontal acc. = 150 gal

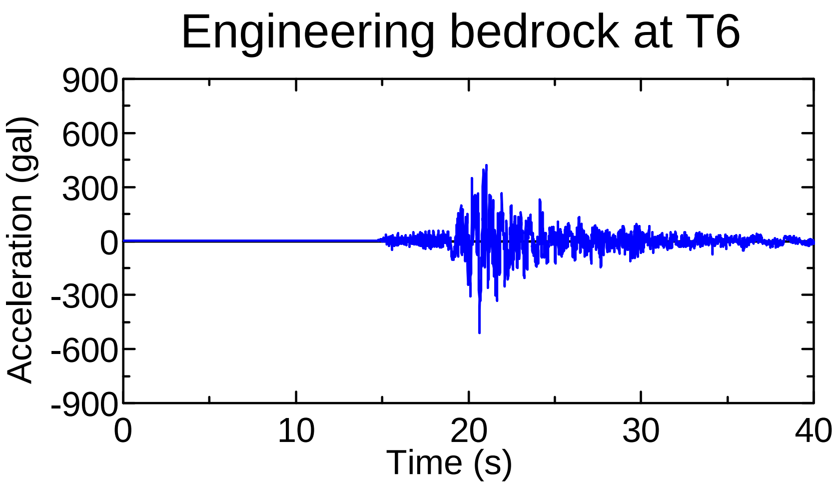
As the reason decided to be 150gal, Again trial and error adjustment of the acceleration was carried out until the safety factor of the embankment is nearly equal to 1.0

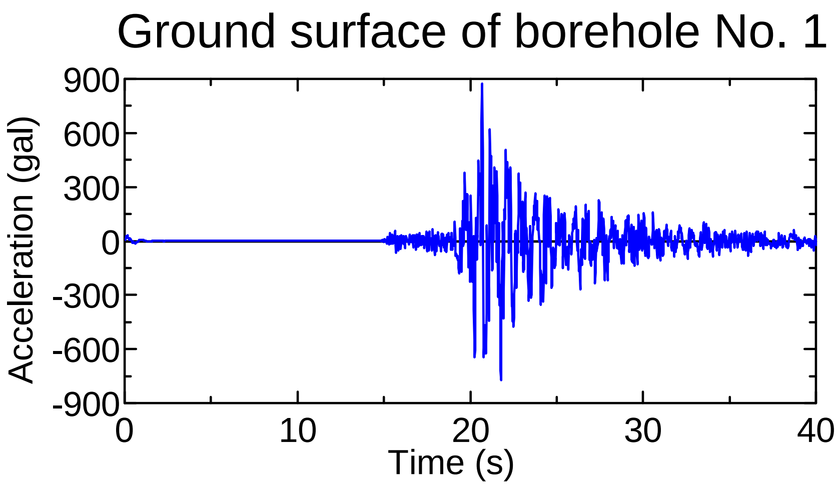
But…

Parametric Study Results (include equivalent static hor. acc.)



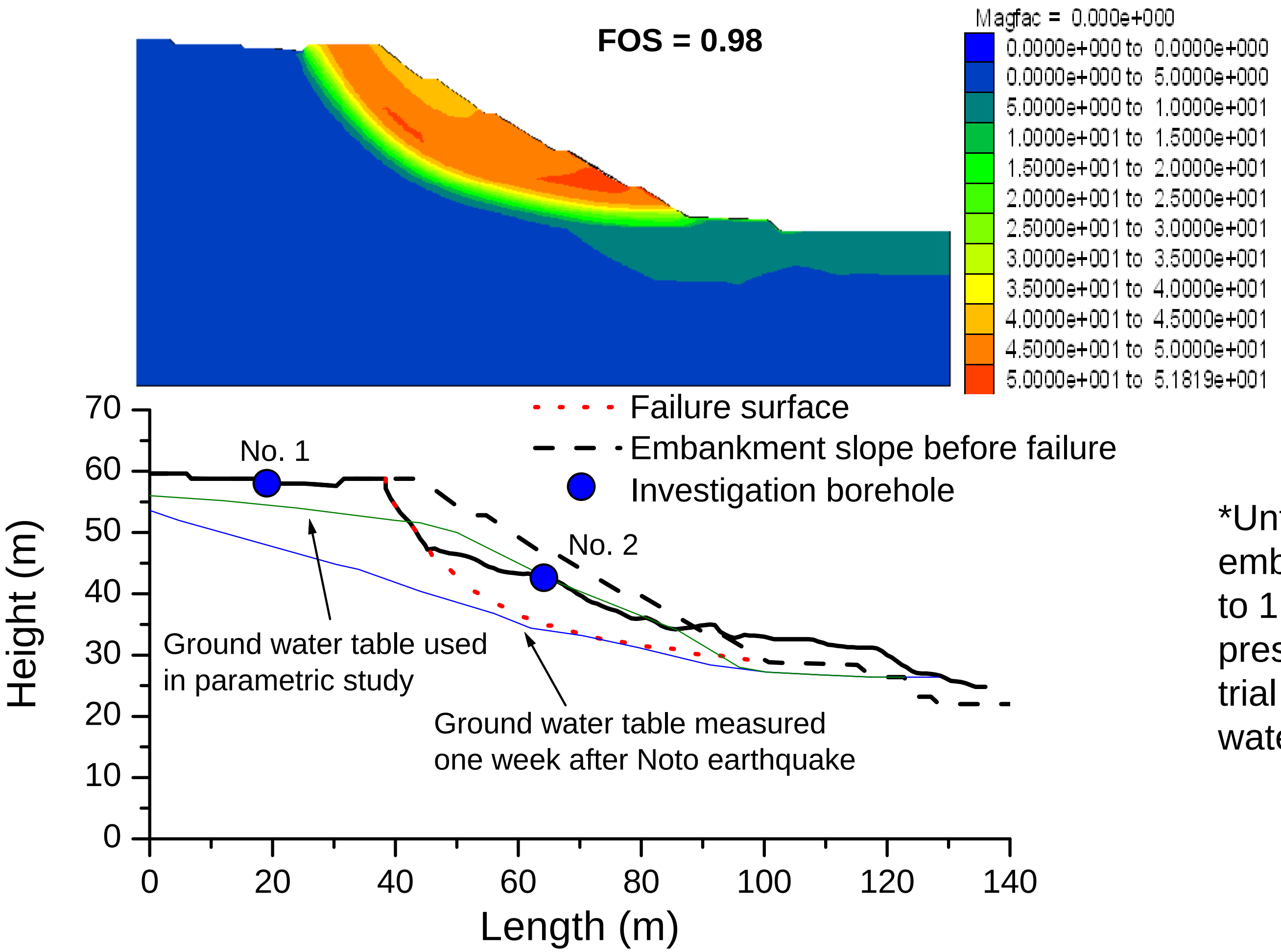
Equivalent static horizontal acc. = 150 gal





The equivalent static horizontal acceleration is quite small compared with estimated dynamic excitations at the embankment. This is thought to be due to the kinematic effect of the dynamic problem is not taken into account in the analysis.

Parametric Study Results
–considering the difference between water table level



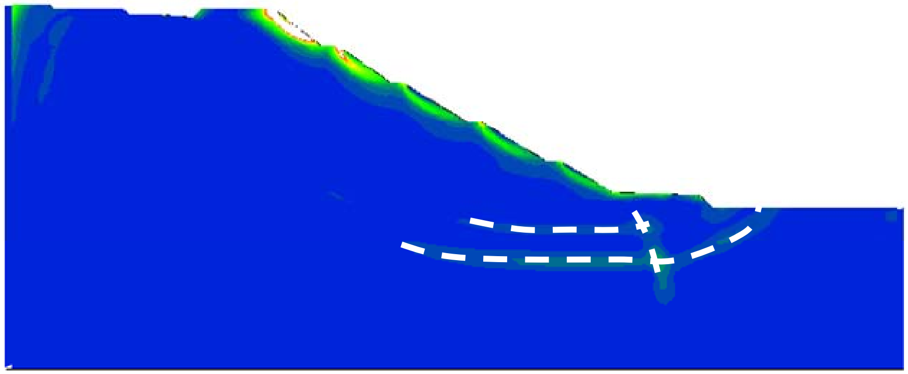
*Until the safety factor of the embankment is nearly equal to 1.0, the effect of pore water pressure was investigated by trial and error adjustment of water table level.

Comparing the calculated resulting failure surface at the site, the failure surface due to the effect of pore water pressure is similar in shape.

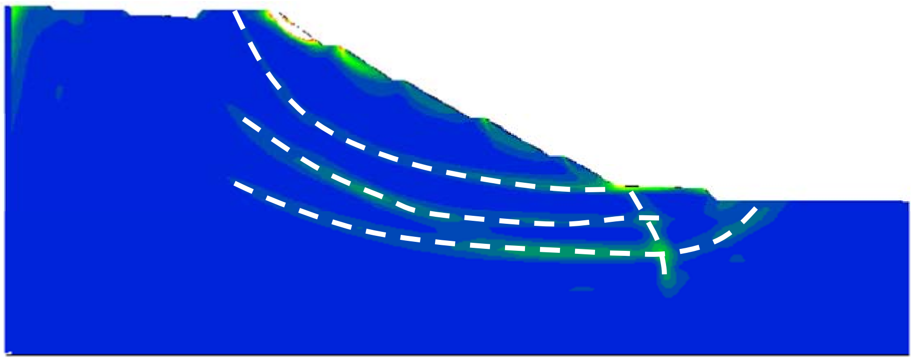
The excess pore water pressure generated during earthquake is one of the key influential factors of the embankment failure.

Results - Dynamic Analysis

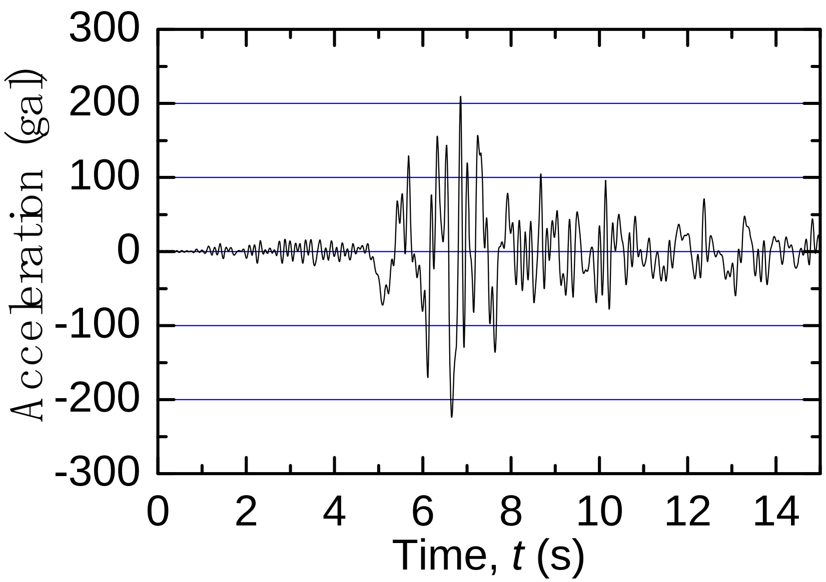
White line is the area of >3% share strain obtained.

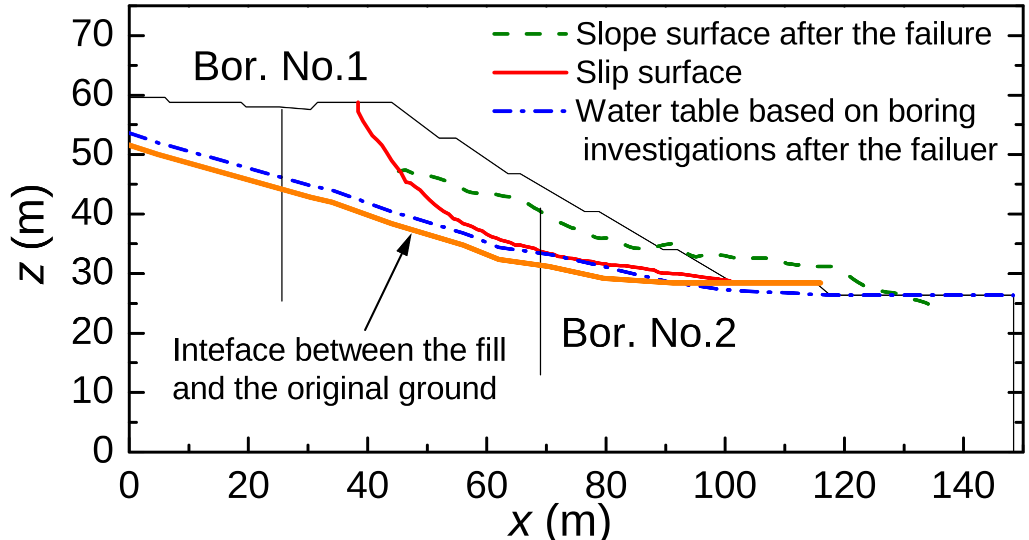


Using measured ground water table
(t = 8.5sec)



Using higher ground water table
(t = 8.5sec)





Conclusions

- There were failures of road embankments in some localities in the earthquake region during the 2007 Noto earthquake.
- The geomechanical parameters were obtained from the laboratory tests of the soil sample collected from the site.
- The excess pore water pressure generated during earthquake is one of the key influential factors in the failure of embankment.

Thank you for your attention!

Question?

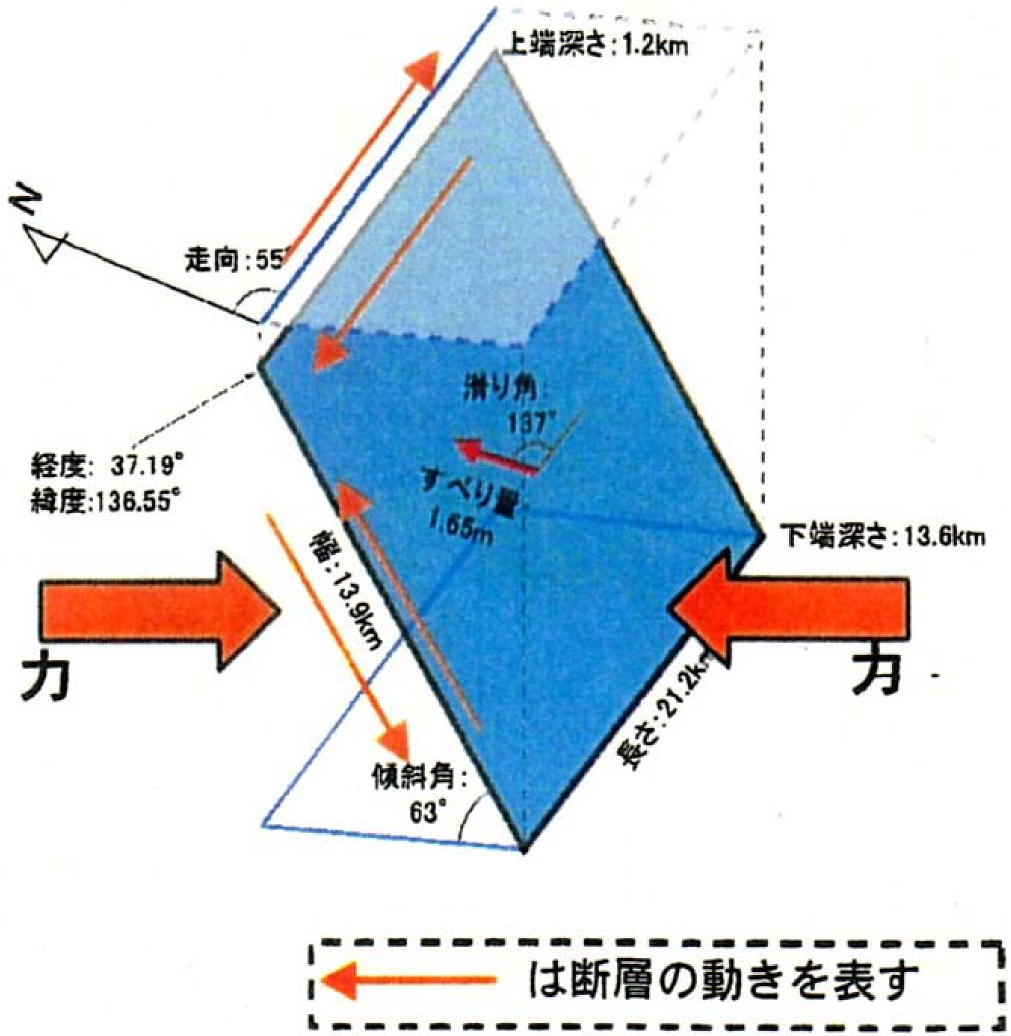
Please contact via e-mail:

kitiyodom@yahoo.co.jp

or

murata@t.kanazawa-u.ac.jp

能登半島地震



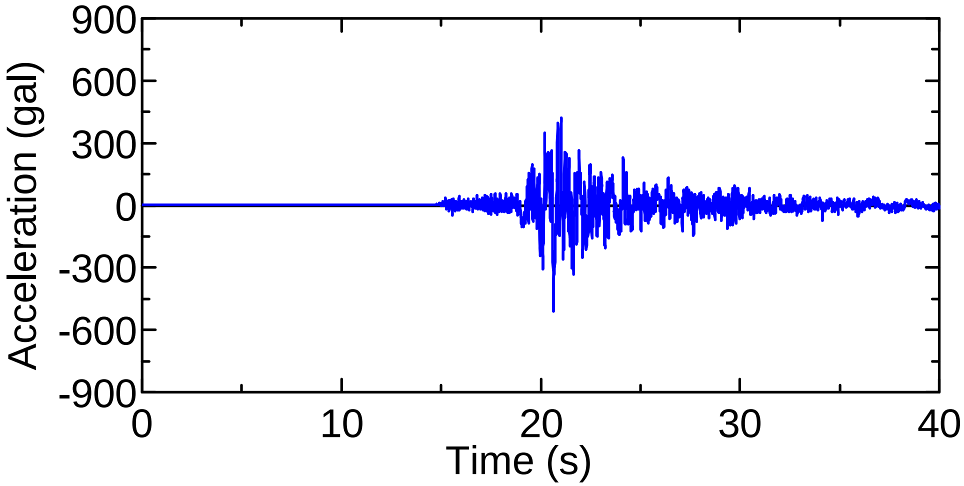
震源断層：

37.19° N, 136.55 ° E

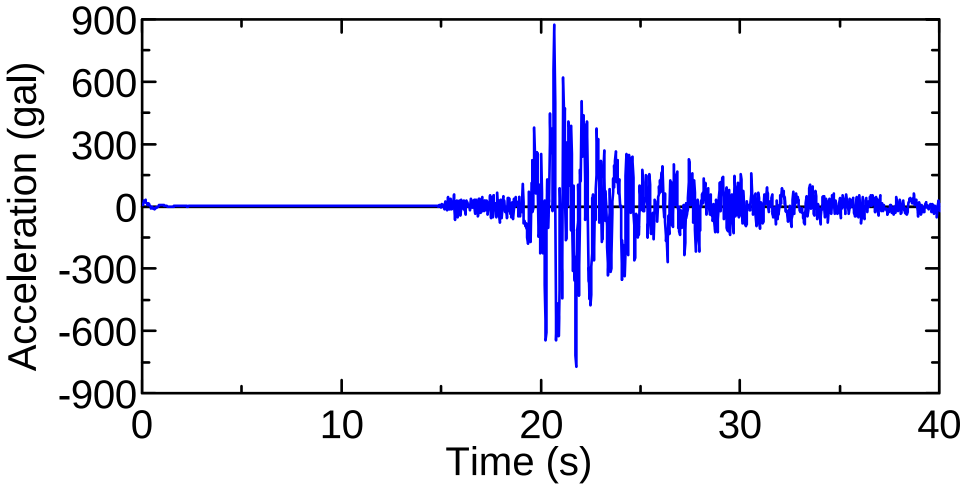
1.2kmの線を上端として，南東方向に約63° の傾斜角で下がる面をもつ横ずれ逆断層

震源断層の概念図（国土地理院資料）

Input Dynamic Excitation



Engineering bedrock at T6



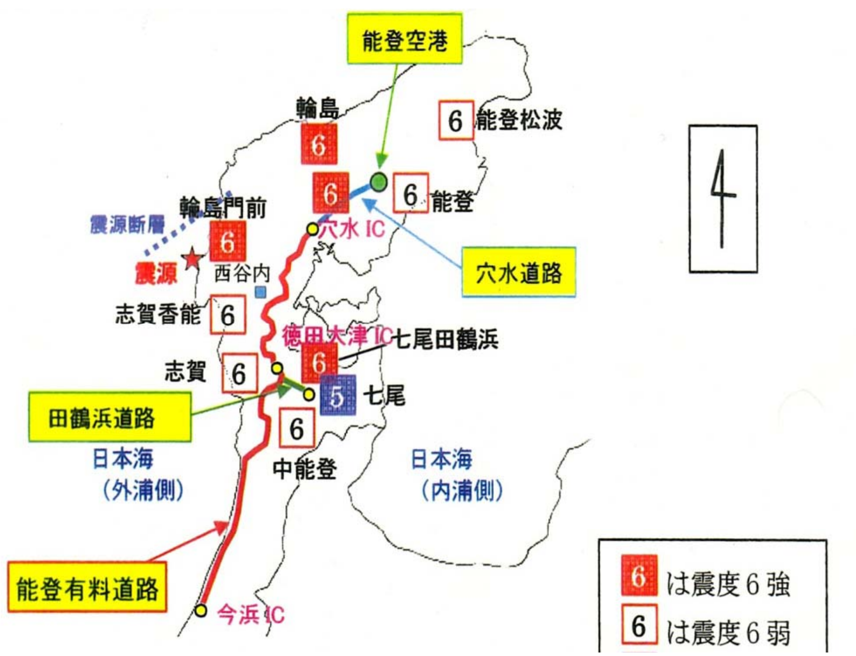
Ground surface of borehole No. 1

盛土崩壊の要因及びメカニズム

（能登有料道路復旧工法検討委員会　土工部会　川村國夫委員長）

大きな地震動によって，盛土体が強く揺さぶられることにより強度が低下し，安定性を失った。

能登有料道路上り線側（内浦側）の盛土の崩壊が顕著であることから，外浦側から内浦側に向かう強い揺れが引き金であったと想定される。



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崩壊に至るメカニズムとしては，沢地形における盛土部の崩壊が多いことから，水分を多く含む盛土が地震動による急激に揺さぶられることにより，盛土内部の水圧が高まり，盛土本体の強度が低下したか，あるいは，盛土下の基礎地盤が地震動による強度低下し，盛土を支えきれずに崩壊に至ったと推察されるが，引き続き調査が必要。

復旧工法設計の提案
（能登有料道路復旧工法検討委員会　土工部会　川村國夫委員長）

1. 盛土体の靭性を向上させ，壊れにくい道路とするため，ジオテキスタイル等を用いて盛土を行う。
2. 基本的には，崩壊して緩んだ土を再利用して復旧工事を行うため，必要に応じて石灰等を混合して改良し，強度確保と施工性の向上を図る。
3. 盛土の中に水を入れないための地表面の排水対策及び盛土内の含水比を速やかに低下させる排水対策（地山と盛土との境界および盛土内に排水層を設置）に留意した施工を行う。
4. 盛土本体内の間隙水を速やかに排出するための耐圧性ドレーン等を敷設する。
5. 盛土全体の安定を向上させるため，法尻部に崩壊残土による抑え盛土と大型ふとんかご工を施工する。