9th May 2024
8ICEGE

The 2024 Noto Peninsula Earthquake
- Liquefaction and lateral flow damage -

Hirofumi TOYOTA
Department of Civil and Environmental Engineering
Nagaoka University of Technology

Acknowledgement: I have used the data offered by Japan Metrological Agency, National Institute of Advanced Industrial Science and Technology, and Ministry of Land, Infrastructure, Transport and Tourism. I have also used the information from my colleagues and the member of reconnaissance team in Japanese Geotechnical Society.

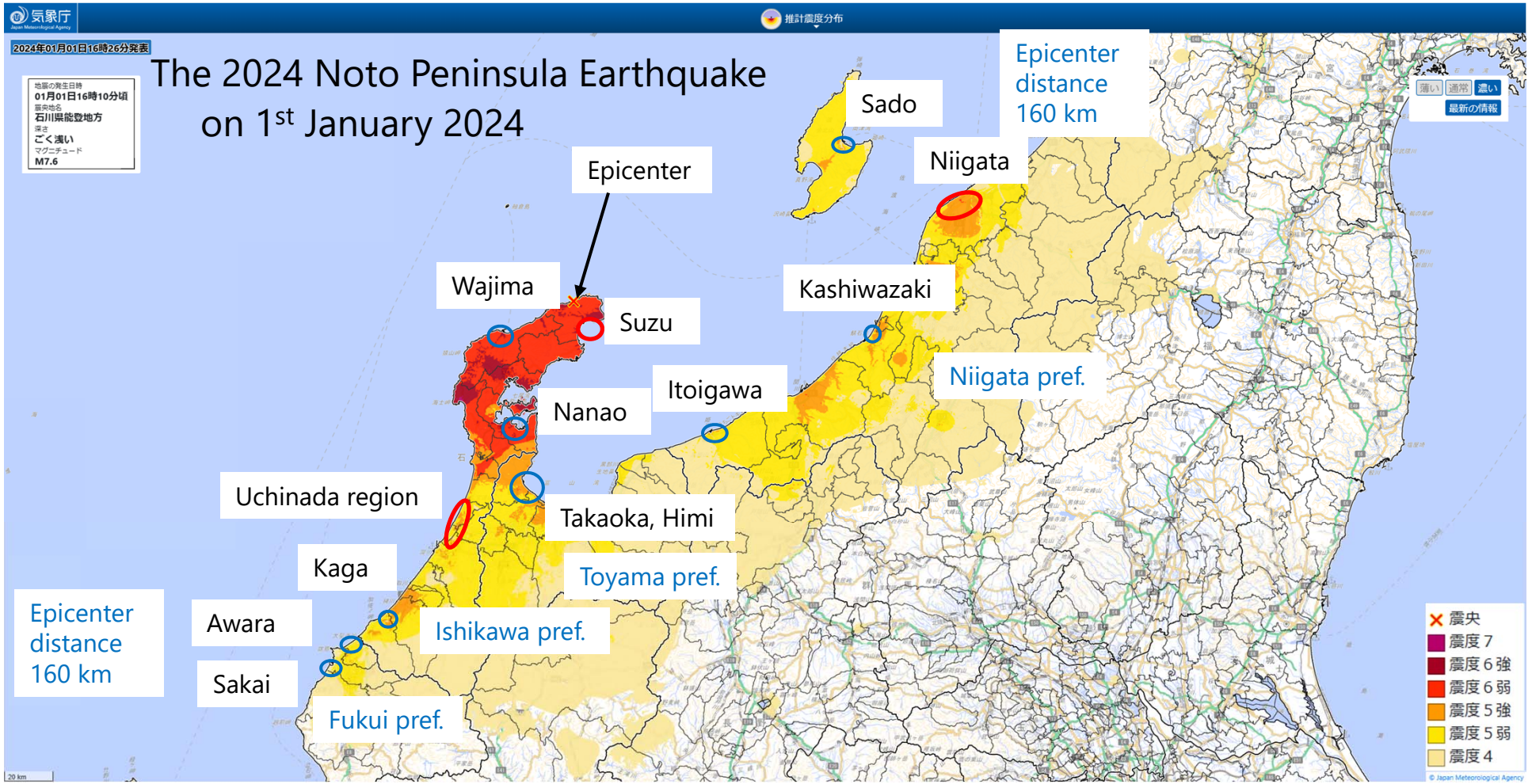
I offer my condolences to those who were affected by the disaster.

Contents

- Liquefaction damage in Niigata city
- Liquefaction damage in Uchinada region
- Other liquefaction damage
- Summary

Liquefaction damage area

Only large damage area



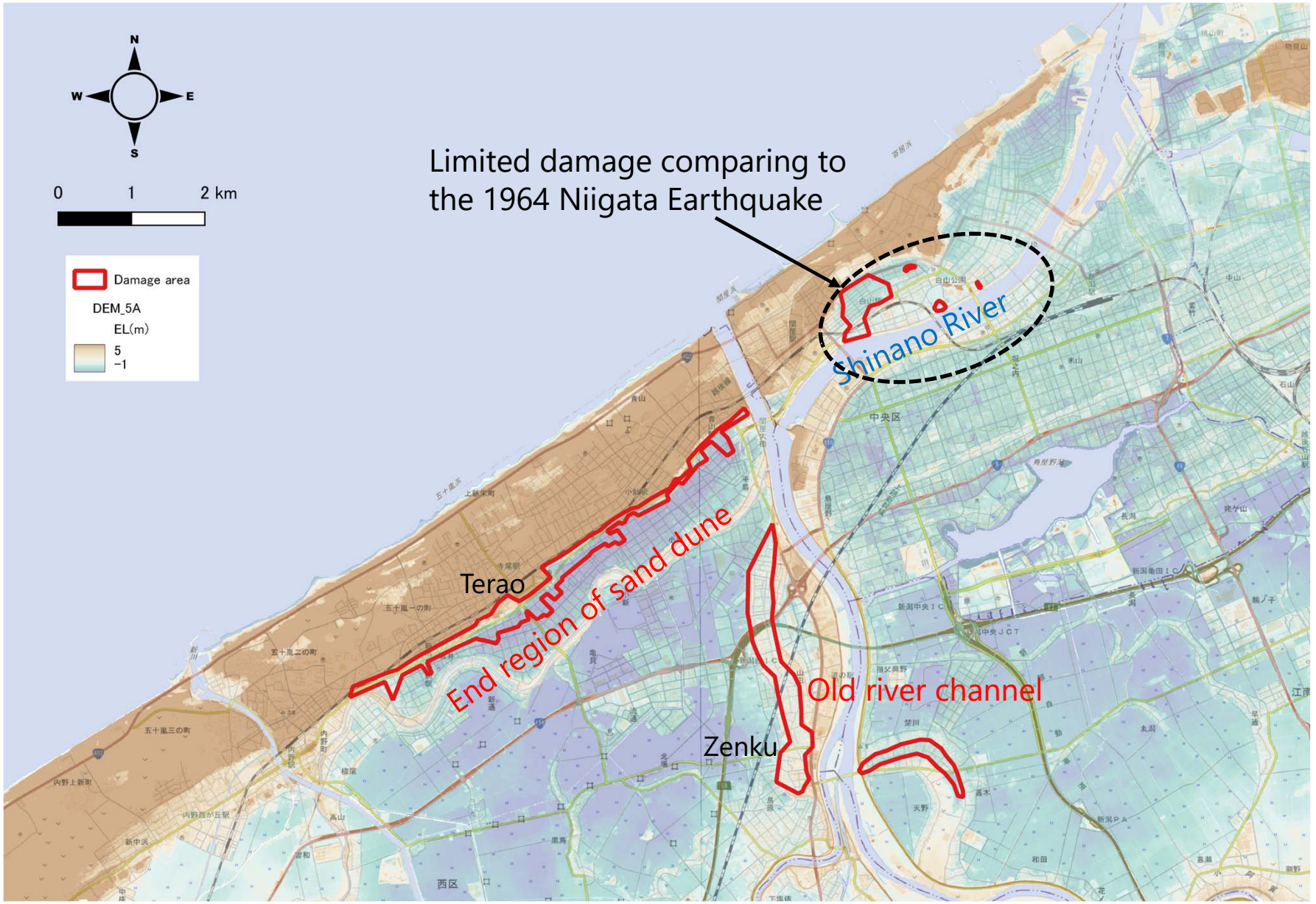
Estimated JMA seismic intensity

Liquefaction damage in Niigata city

- End region of sand dune (Nishi-ku: Terao area)
- Former river channel (Nishi-ku: Zenku)

Main liquefaction area in Niigata city

KOWA Co., Ltd.



Investigation is in progress

Niigata city

Towhata, et al.: Air photographs of the Niigata city after the earthquake in 1964, JGS, 1999.

Lateral flow during the 1964 Niigata Earthquake

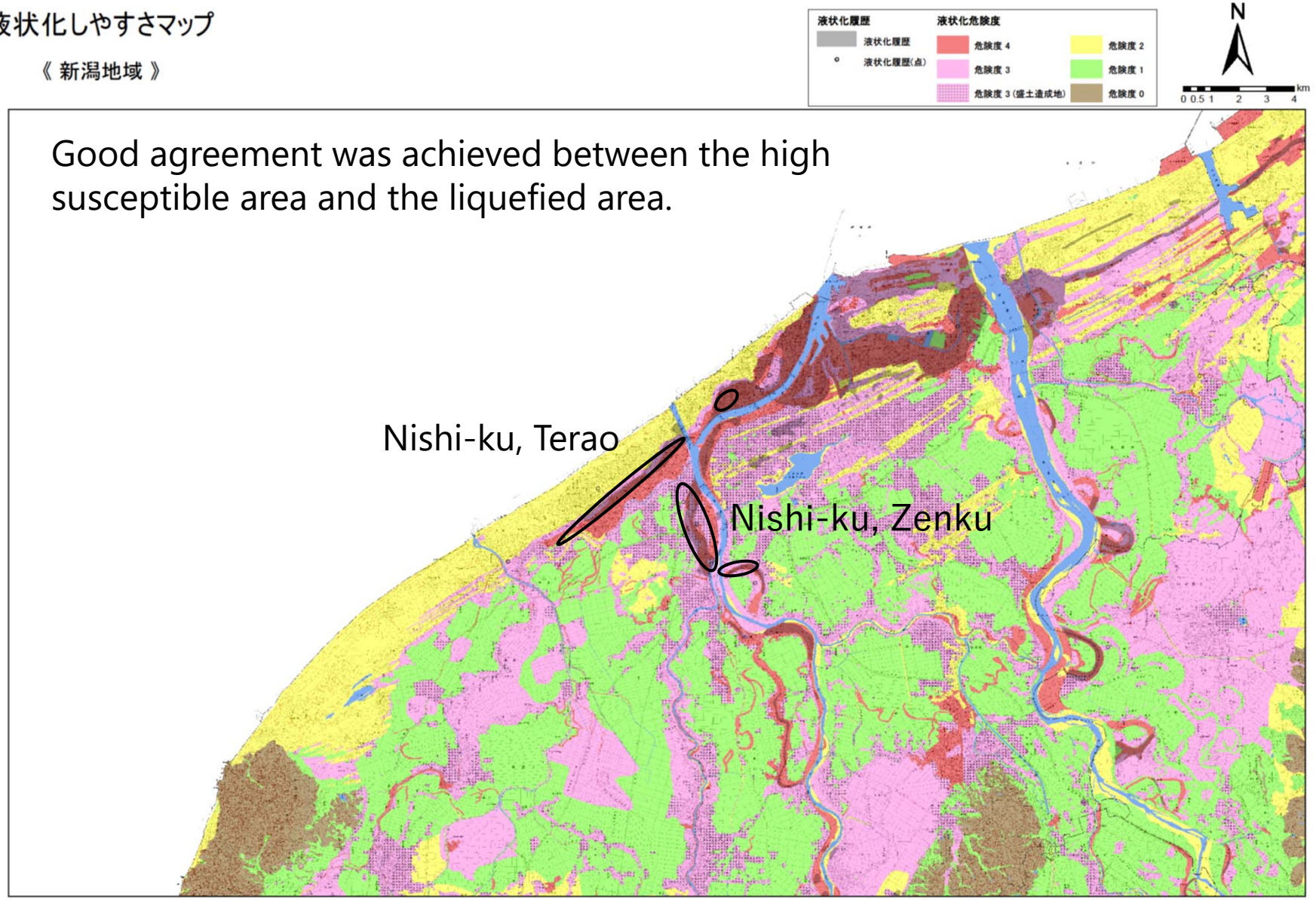
図—6 新潟市の地盤永久変位測定結果および新潟

Hamada, et al.: Observation of permanent ground displacements induced by soil liquefaction, Journal of JSCE, No. 376, 1986.

Liquefaction susceptibility map in Niigata city

液状化しやすさマップ

《 新潟地域 》

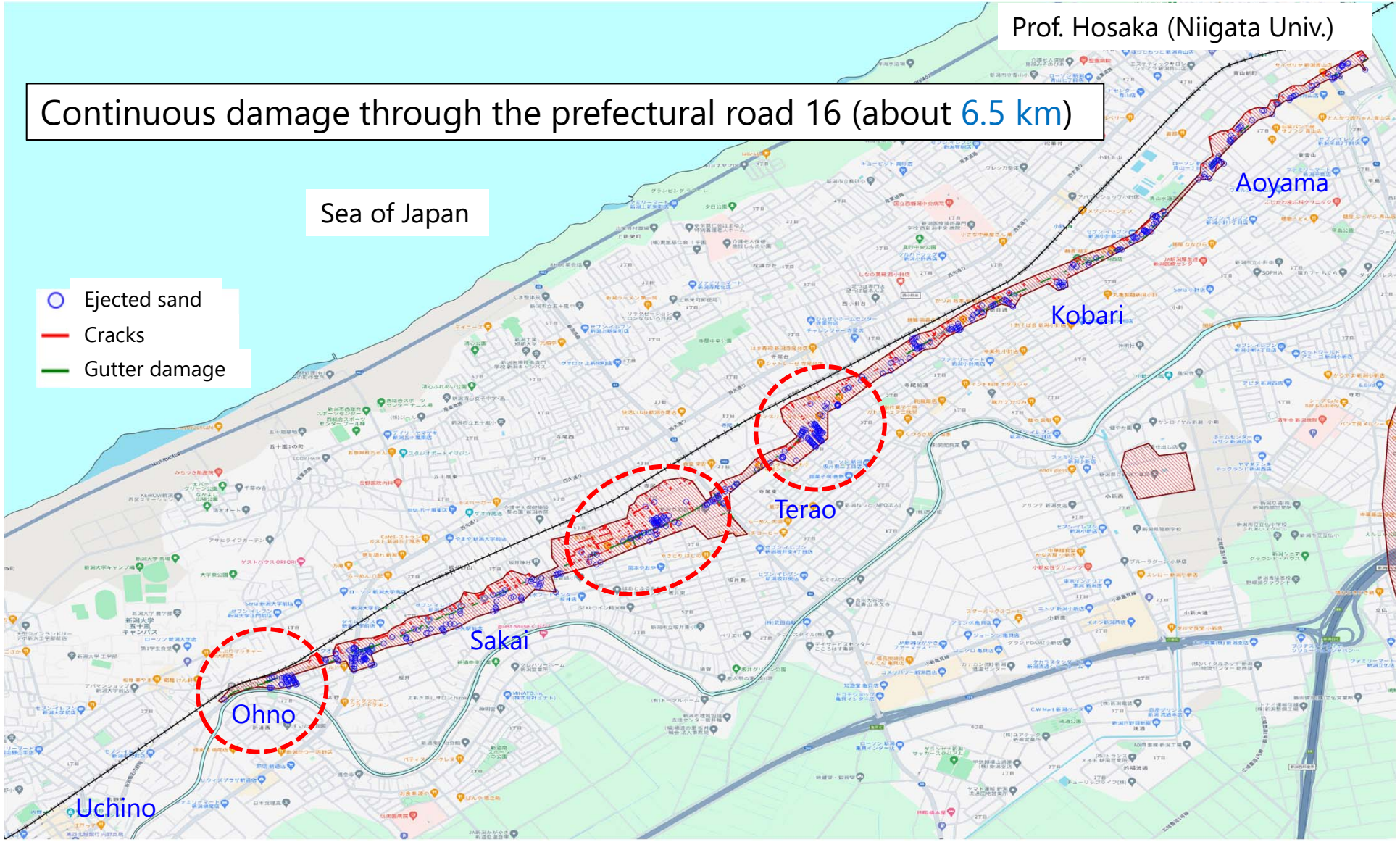


この図面は、5万分の1土地分類基本調査(地形分類図)新潟県発行(1971~1999)の一部を使用して作成した。

液状化履歴は、「若松加寿江(2011)日本の液状化履歴マップ745-2008(東京大学出版会)による。

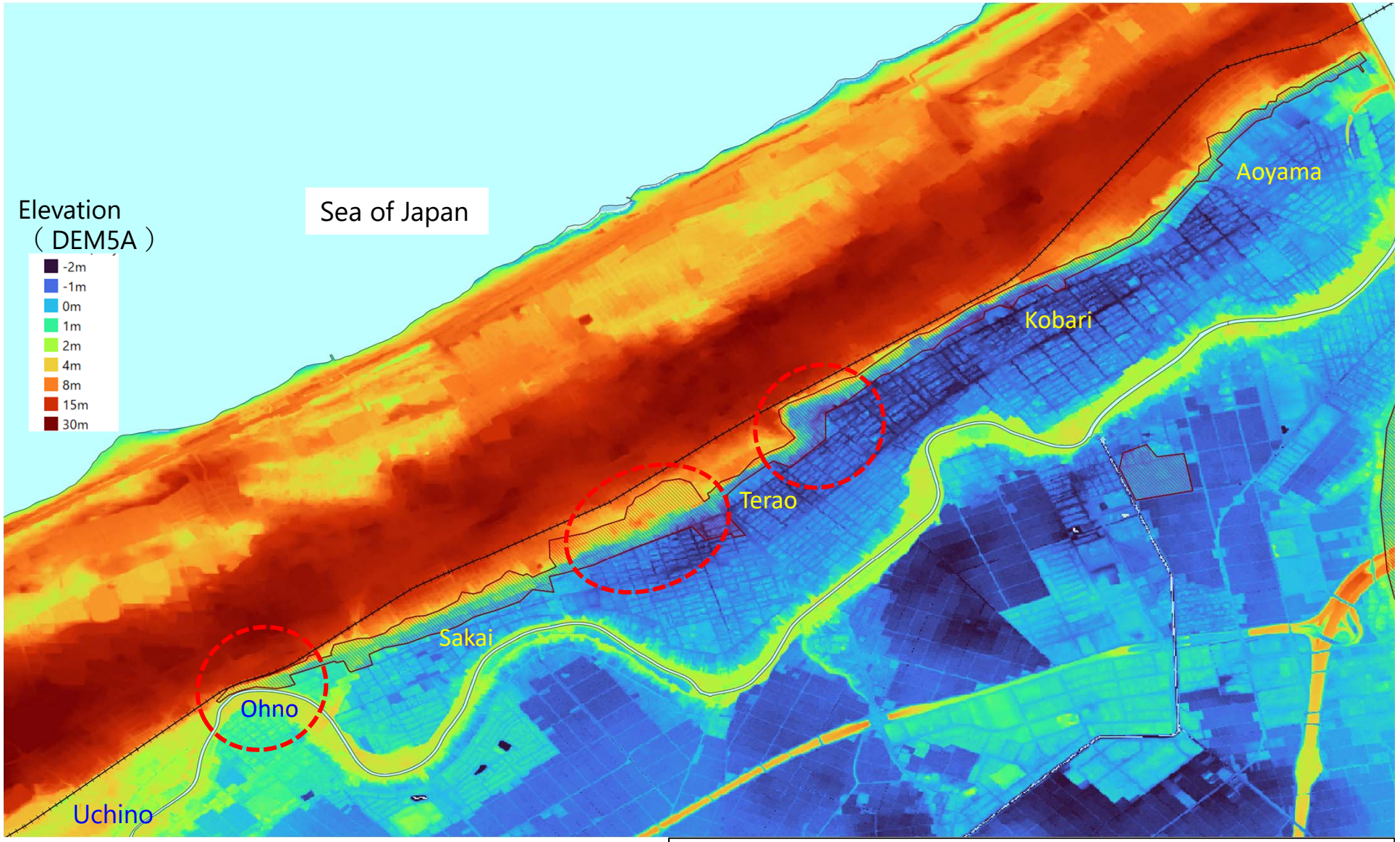
本マップには、過去の液状化履歴が○印でプロットされていますが、原典(若松,2011)では、地震毎にシンボルが変えられており、また液状化が発生した地点の確実度によってもシンボルの大きさが変えられています。本マップではこれらを区別せずに同じ記号でプロットしています。

Liquefaction damage area in end region of sand dune



Elevation of damaged area

Prof. Hosaka (Niigata Univ.)

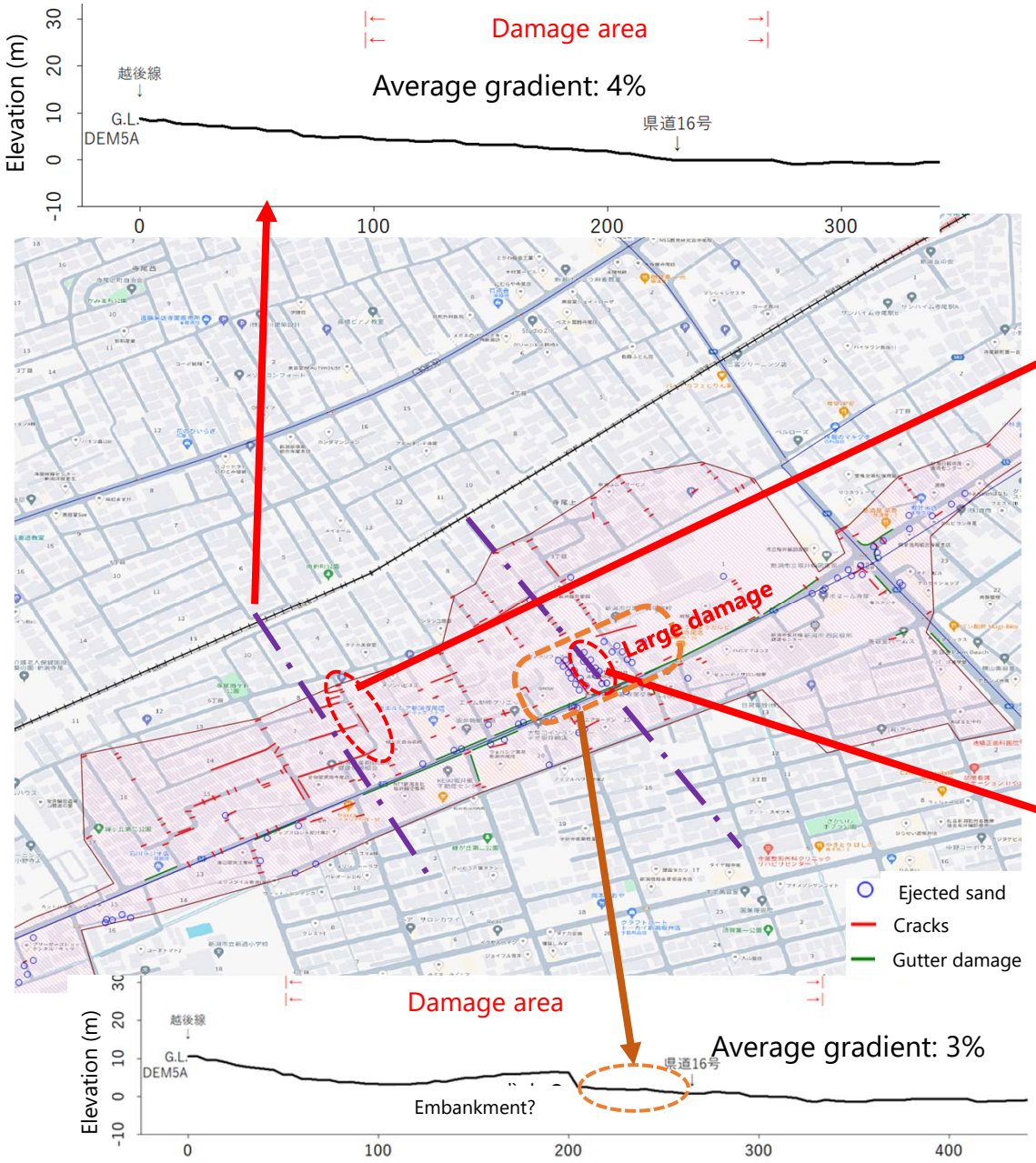


Liquefaction occurred around the elevation of 0 m.

Examples of damage: No. 1

Damage in Sakai area

Prof. Hosaka (Niigata Univ.)



30th Jan.

Upper part of the slope: Open cracks

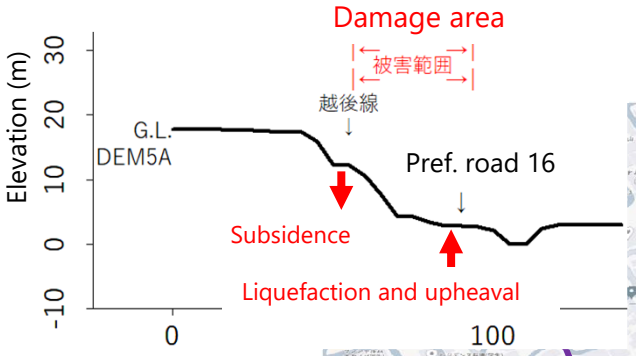
3rd Jan.

Lower part of the slope: Ejected sand and uplift of sidewalk

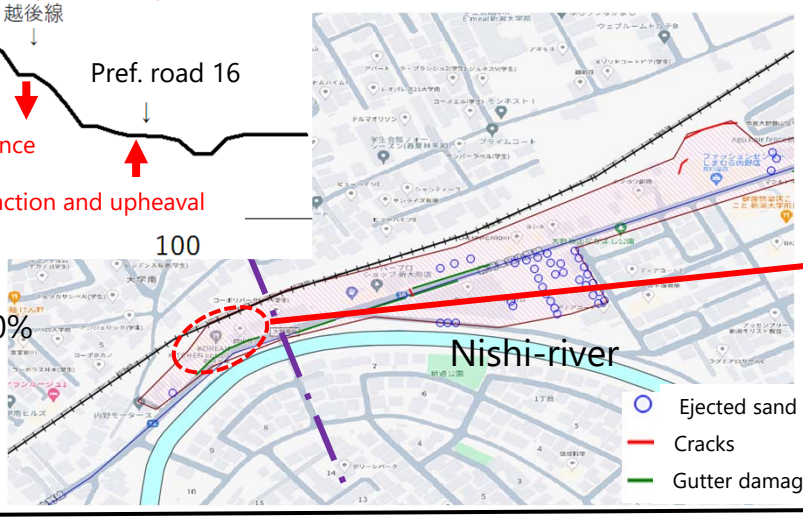
Examples of damage: No. 2

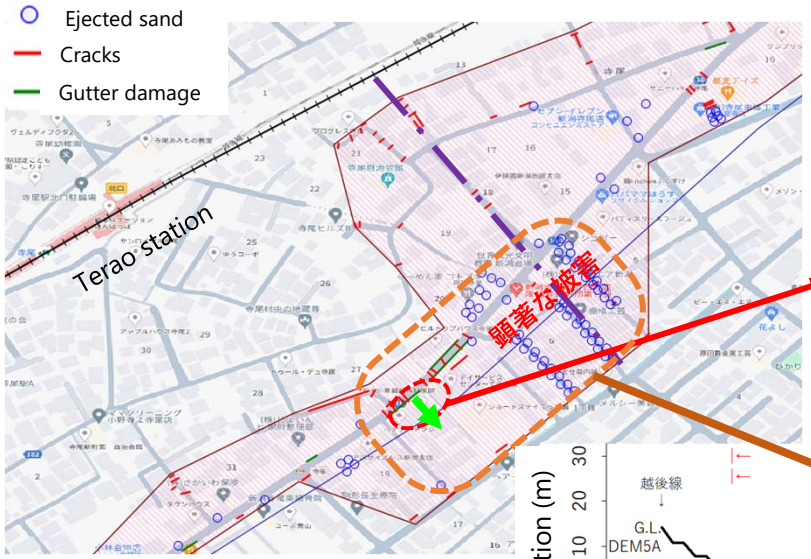
Damage in Ohno area

Prof. Hosaka (Niigata Univ.)



Average gradient: 50%

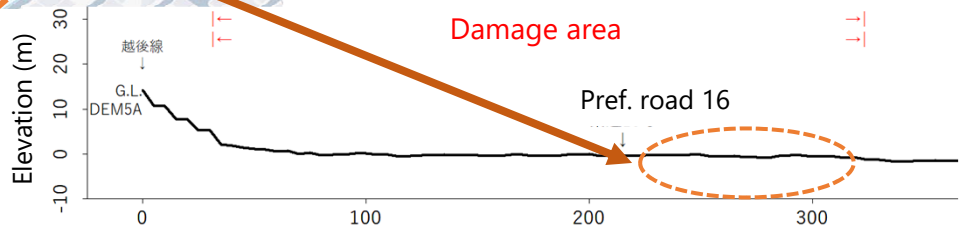




Damage in Terao area

Deformation of the road is slight

Large flow and subsidence

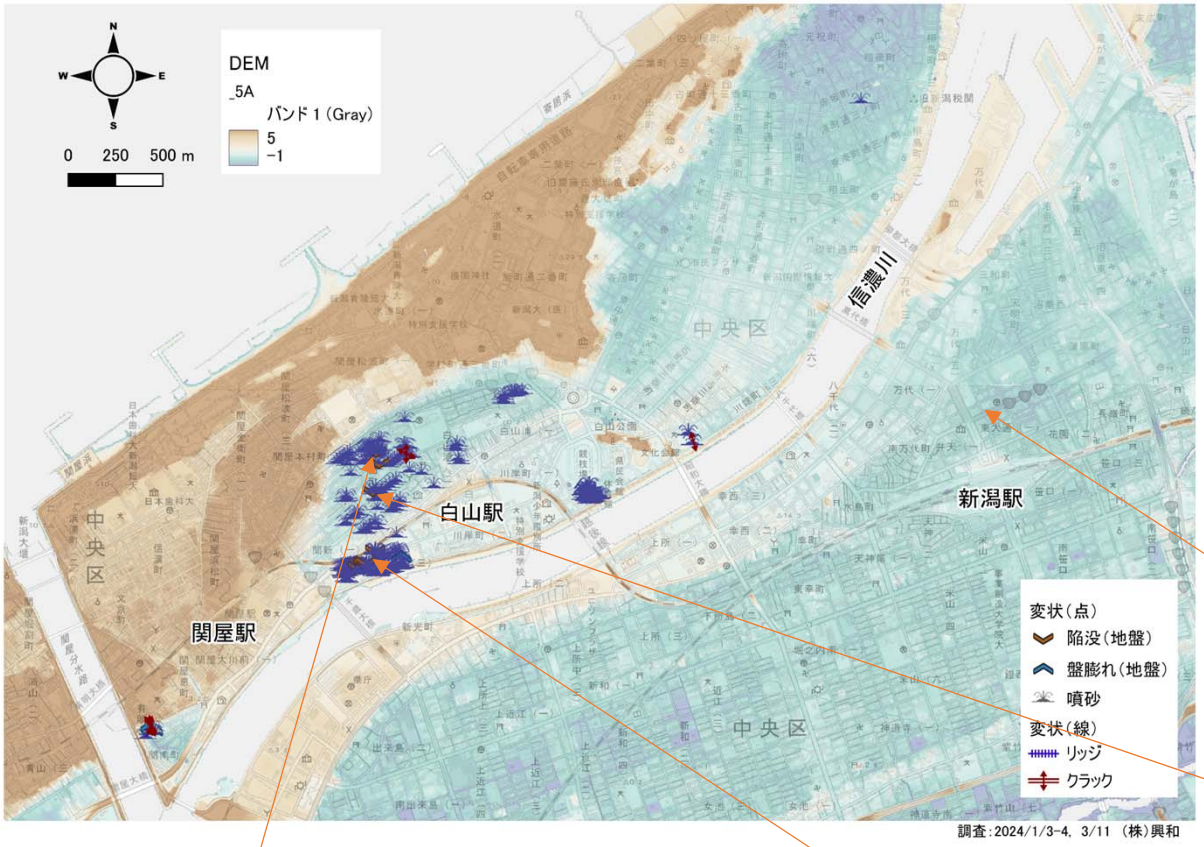


Average gradient: 0.5%

Liquefaction in Chuo-ku (Old river)

KOWA Co., Ltd.

Smaller damage area comparing to the 1964 Niigata Earthquake



Niigata earthquake (June 1964)

2nd Jan.

Higashi-ohdori

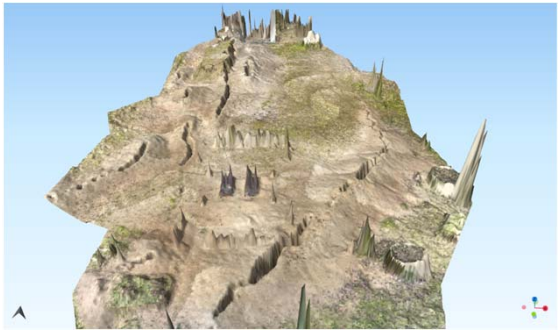
1st Jan.: Sekiyata-machi

4th Jan.: Kawagishi-cho

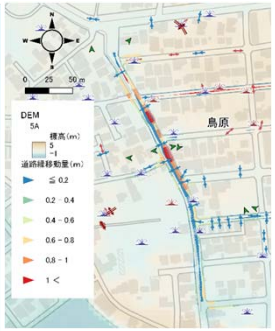
3rd Jan.: Sekiyata-machi

Liquefaction in Toppara and Zenku (Old river)

KOWA Co., Ltd.

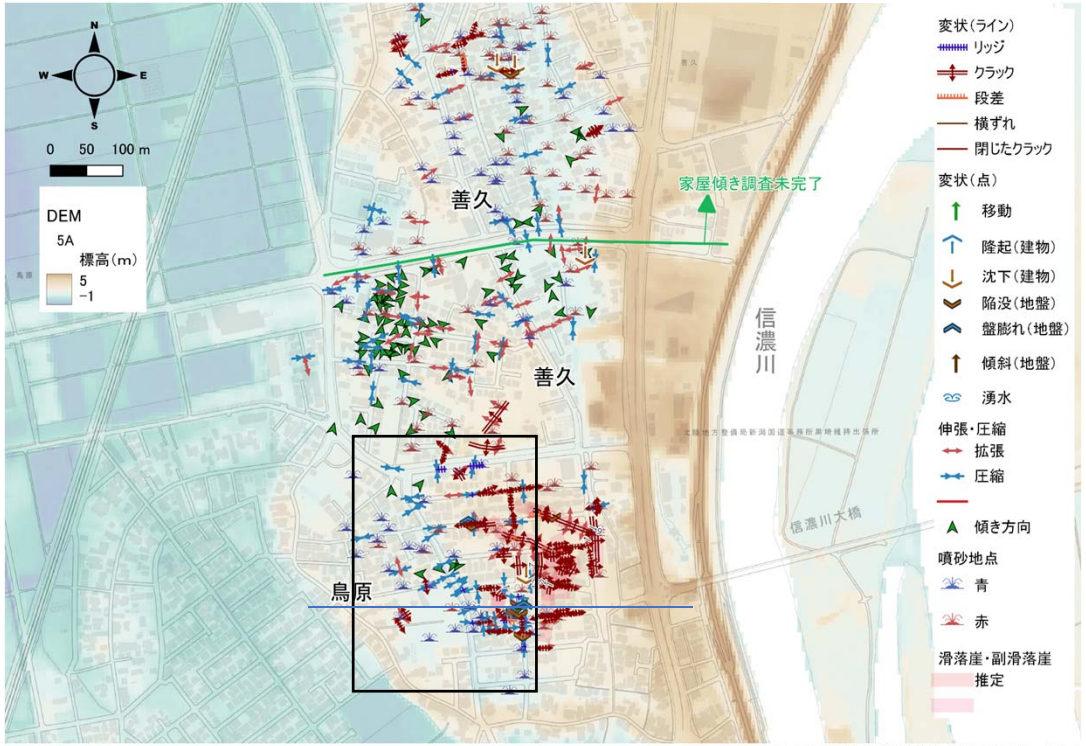


3D for open cracks (17th Jan.)

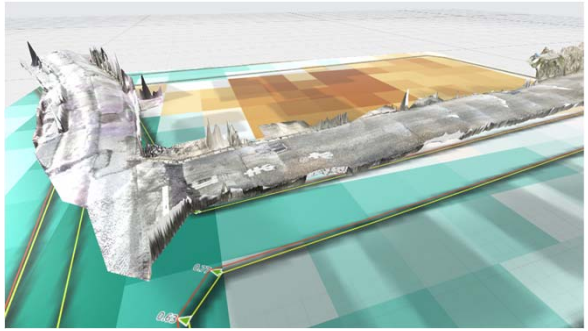


1 m-displacement

Uplift of 40-50 cm in the road



Upheaval of the road (3rd Jan.)



3D for compressional deformation of the road (17th Jan.)

Ejected sand (3rd Jan.)

Leaning and settlement of the house (3rd Jan.)

Liquefaction in Toppara (Old river)

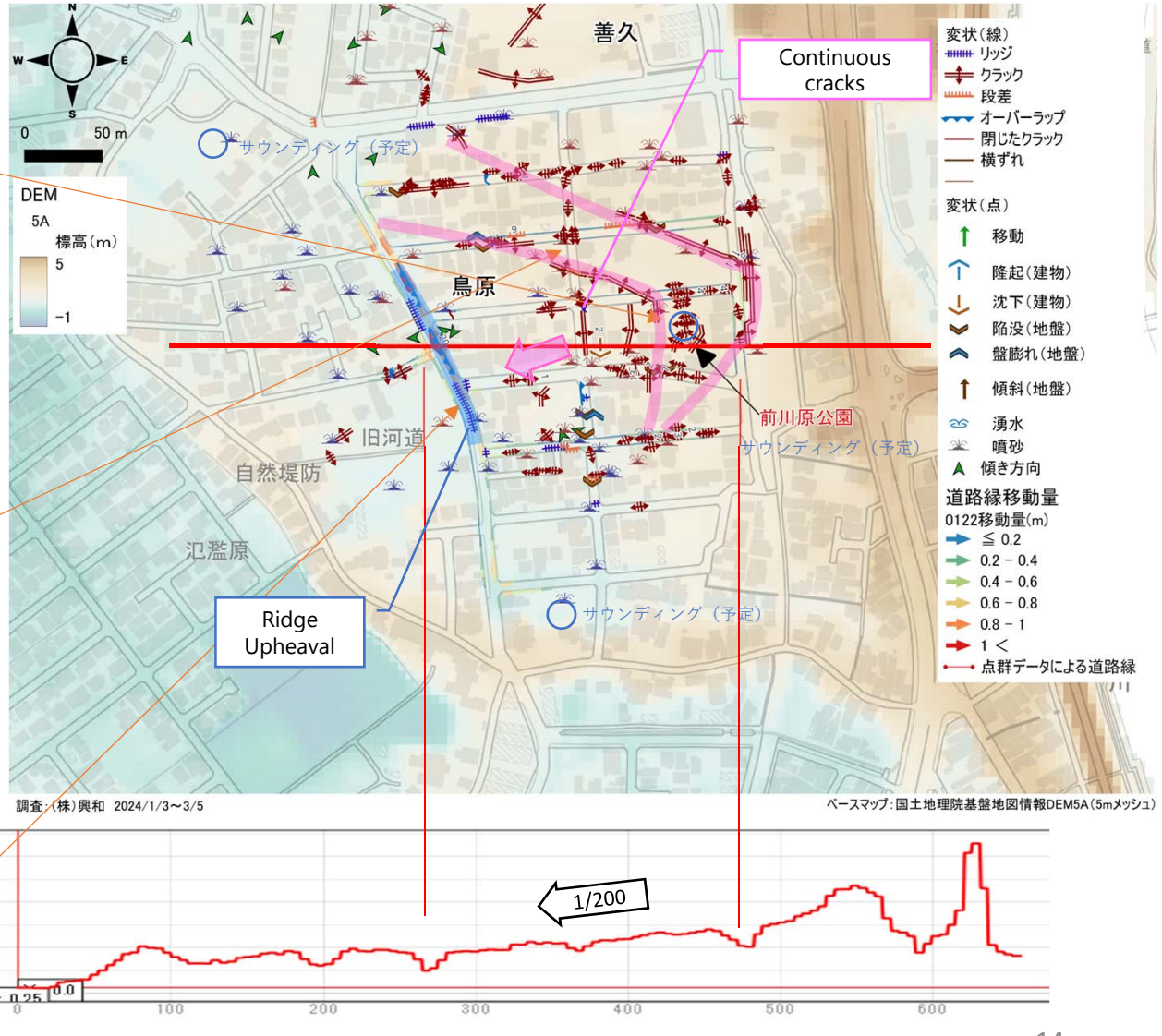
KOWA Co., Ltd.

Lateral flow occurred in very gentle slope (1/200)

4th Jan.

3rd Jan.

3rd Jan.



Cross section profile

Liquefaction damage around Uchinada

- End region of sand dune

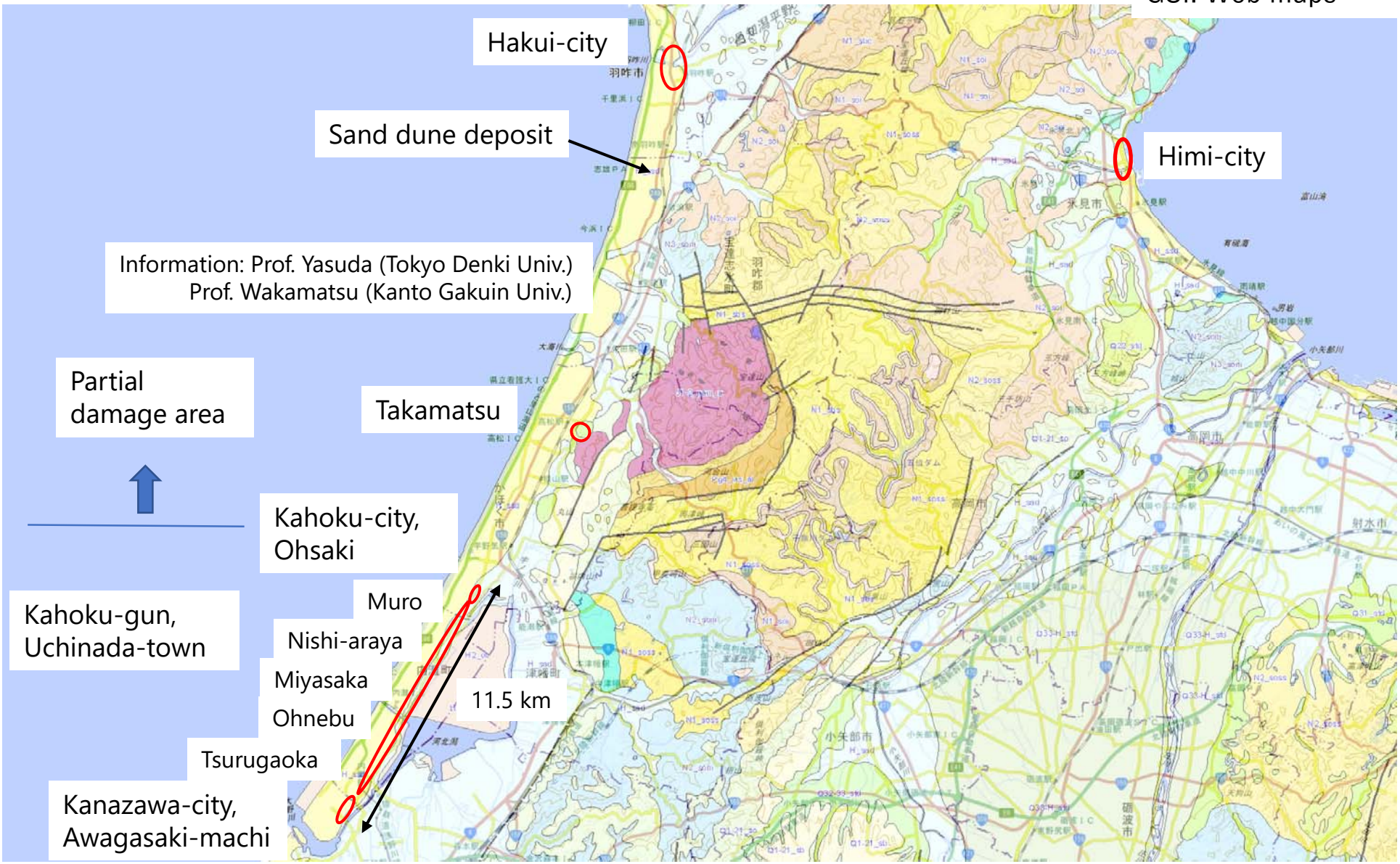
  (Kanazawa-city, Kahoku-gun, Kahoku-city, and Hakui-city)

Reliquefaction
Cracks and ejected sand were reported in Ohnebu, Nishi-araya, and Takamatsu during the 1891 Nobi Earthquake.

Information from Prof. Wakamatsu (Kanto Gakuin Univ.)

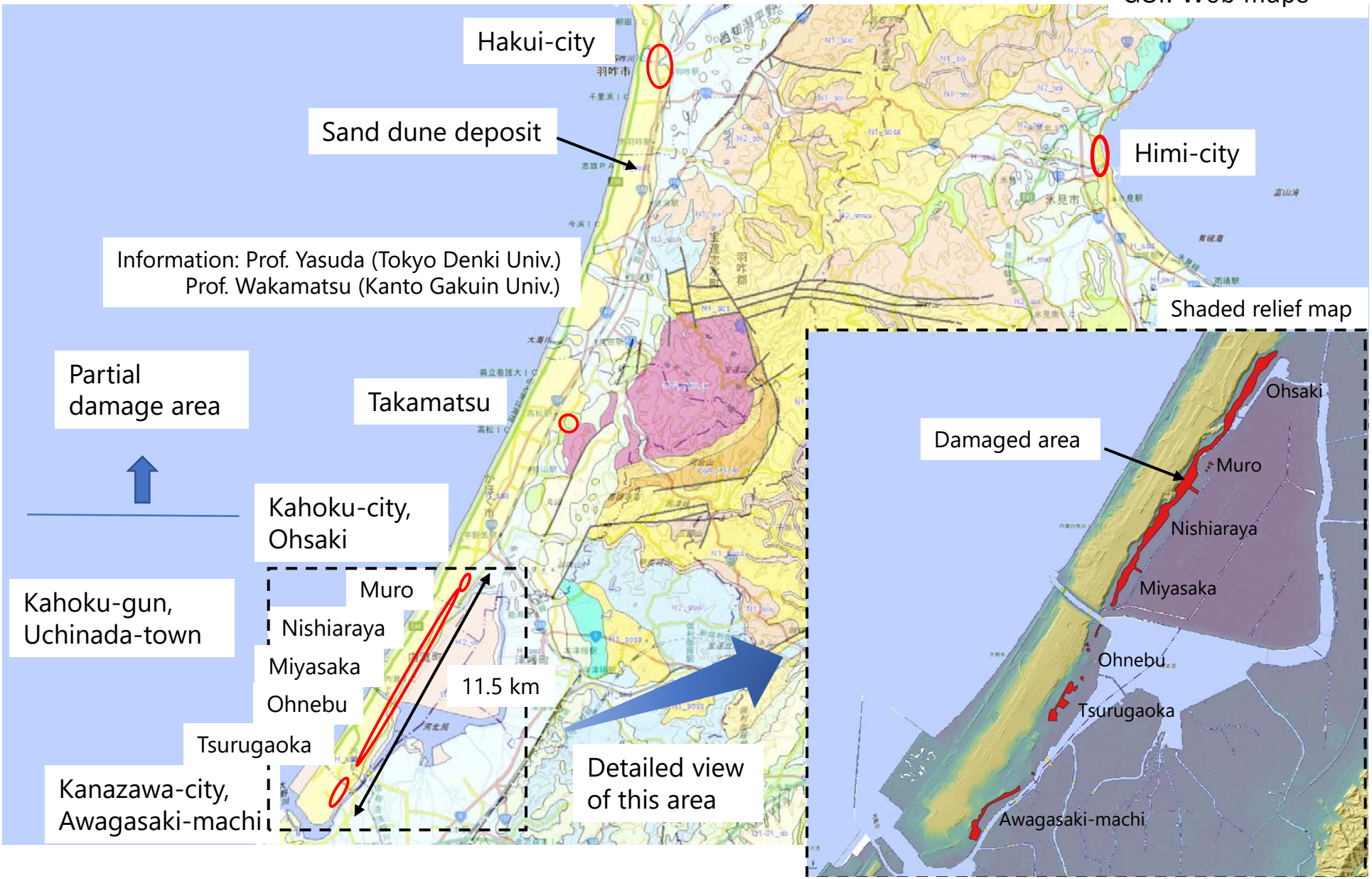
Extending damage along the end region of sand dune

AIST: GeomapNavi
GSI: Web maps

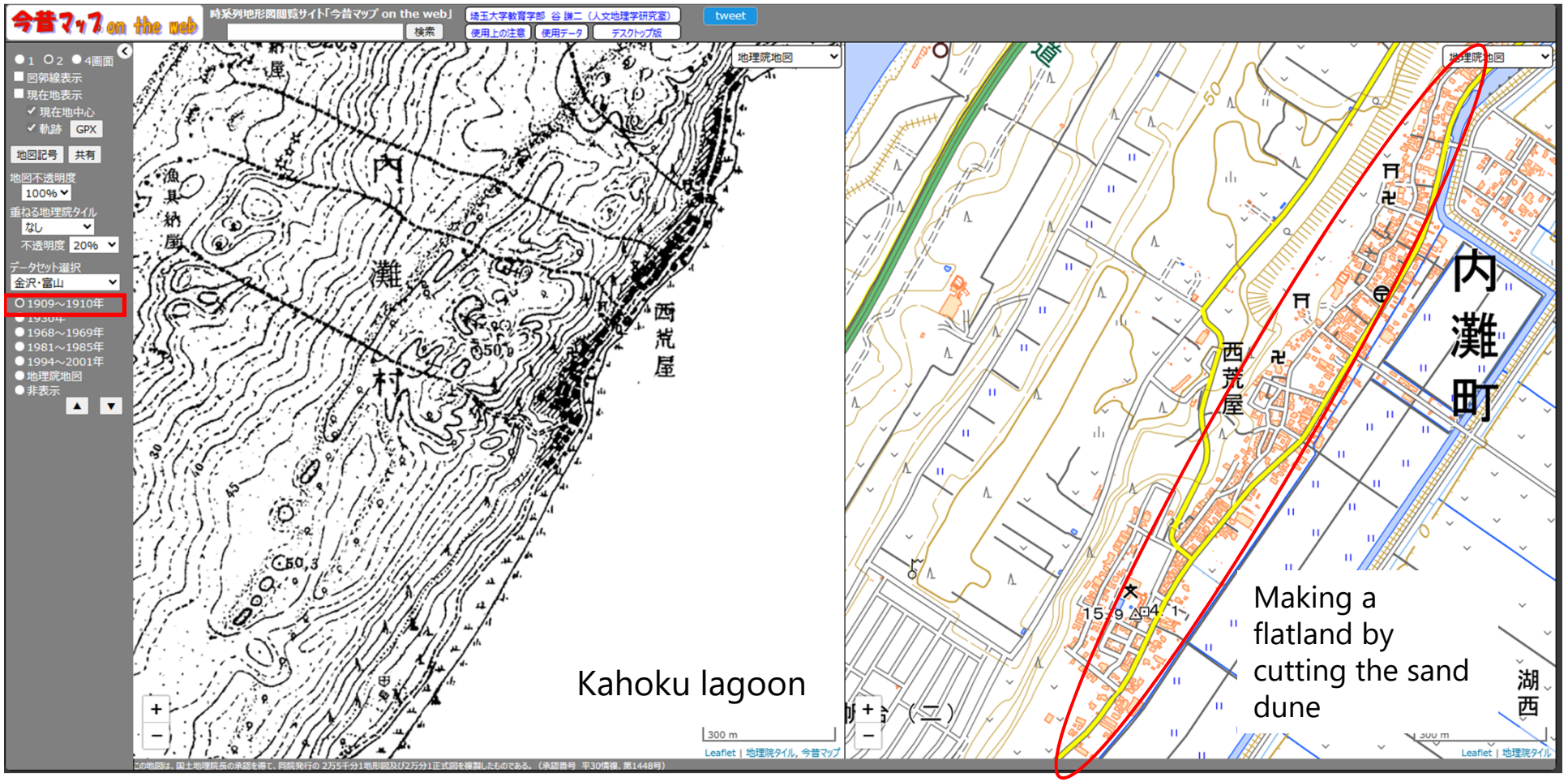


Extending damage along the end region of sand dune

AIST: GeomapNavi
GSI: Web maps



Uchinada-town



- There was steep slope of sand dune close to the lagoon in the early 1900's.
- The sand dune was cut to use for reclamation works (northern part of Ohnebu).
- Large damage occurred in cutting slope area between Miyasaka and Ohsaki.

Boring data

土質ボーリング柱状図（標準貫入試験）

調　　査　　名

事業名または工事名　　北陸農政局河北潟干拓建設事業8号橋梁その他土質調査業務

調査目的及び調査対象　　その他 その他

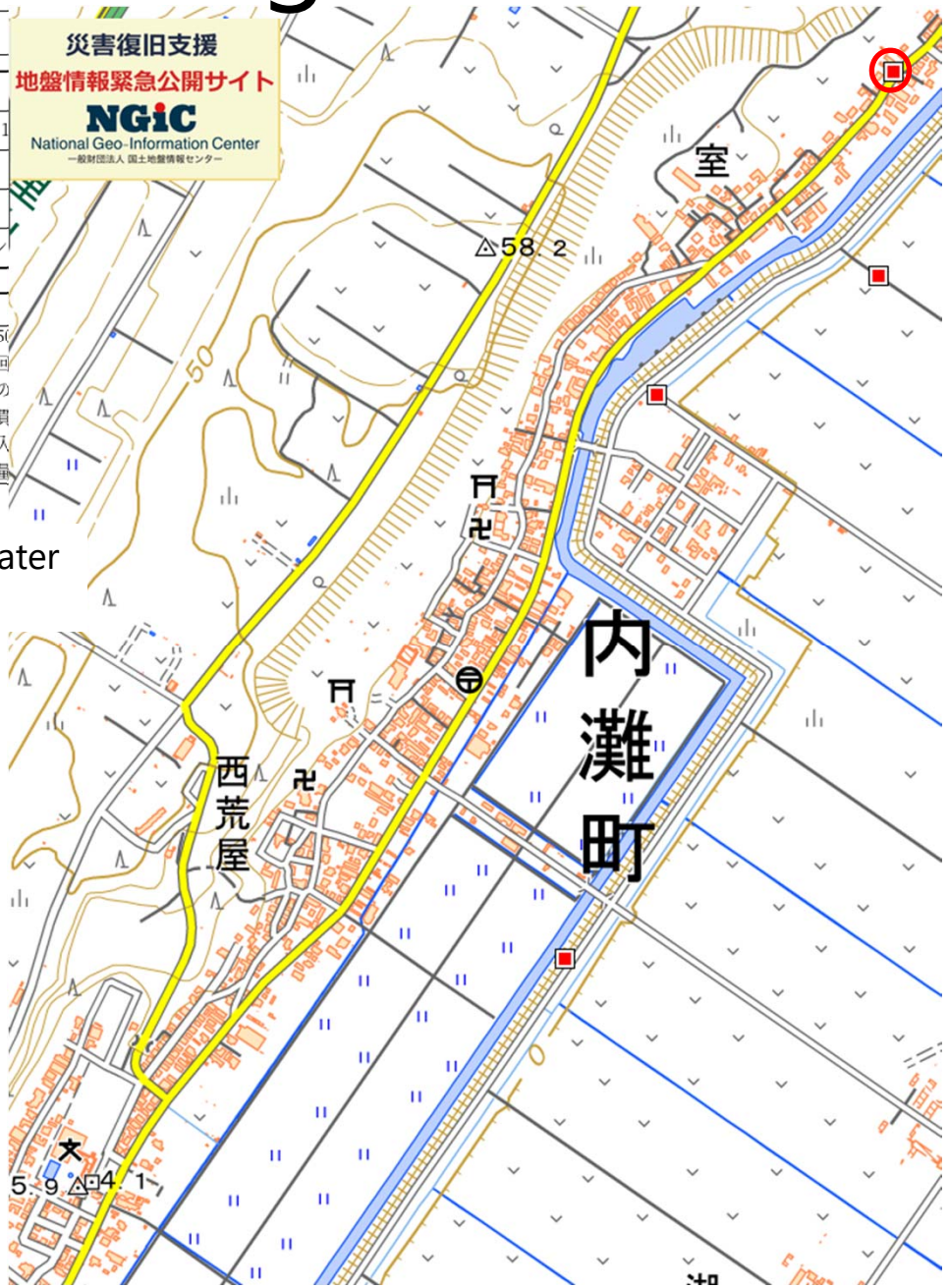
ボーリング名	22-I-1	調査位置	河北潟干拓地内				
発注機関	農林水産省　河北潟干拓建設事務所			調査期間	昭和50年10月14日～昭和50年10月1		
調査業者名	不明　電話(不明)	主任技師	不明	現場代理人	不明	コア鑑定者	不明
孔口標高	T.P. 1.49 m	角度	上 180° 下 0° 90°	方位	北 0° 東 90° 南 180° 西 270°	地盤勾配	水平 0° 鉛直 90°
総削孔長	37.50 m	使用機種	試錐機	ロータリー式			
			エンジン	不明		ポン	

標尺 (m)	標高 (m)	深度 (m)	現場土質名（模様）	現場土質名	地盤材料の工学的分類	色調	相対密度	相対稠度	記事	孔内水位／測定年月日
1						暗茶			上部0.50mまで草根を混入1.50～3.20mまで含水極めて多い。2.30～3.20m間、黒灰色で若干のガス湧出、粒径やや大きく中砂も若干混入、有機物少数点在	10/14 1.34
2									3.20～5.65m茶褐色又は淡茶褐色を呈し、シルト分微量含み均質	
3									5.65～6.15m黒灰色で粒径やや大中砂も混入	
4										
5										
6	-4.66	6.15		細砂		茶褐色～黒灰色				
7									含水多い、粘性大きくほぼ均質な部分が多いが若干シルト分の含有率が変化する	
8									最上部6.00m～7.00m間シルト、砂質シルトを微層で挟み色の変化あり	
9									8.00～9.00mシルト分少ない	
10									9.00～10.00m附近シルト分中位	
11									全般に絞り出しあり極めて微細1～2m/mの有機物片を少数点在	
12									11.00m附近、白色斑点φ1m/m前後のもの数個点在	
13				シルト質粘土					12.00m附近φ3m/ml=50m/m位のパイプ状管がみられる	
14									中下部もほぼ均質であるが、15.40m～15.50mで細砂の極めて薄層1～2m/m厚を数層挟み小ブロック状でも数個点在	
15										
16	-14.56	16.05				暗灰色				
17	-15.71	17.20		粘土		暗青灰色～白灰色			上下層境やや不明瞭、シルト質分少なく粘性極めて大きい、下部白灰色を呈す	
18				シ					混入物はほとんどなし	
									18.00m附近水平に若干色調の変化がみられる	
									18.00m以深暗灰色となる	

標準貫入試験 N値	深度 (m)	10cmごとの打撃回数 0～10	10～20	20～30	打撃ごとの貫入量
5	0.20				5
	0.51	05			31
	5.20	27			27
	5.50	30			30
0	8.20	00			0
	8.63	43			43
0	12.00	00			0
	12.29	29			29
1	16.20	01			1
	16.79	59			59

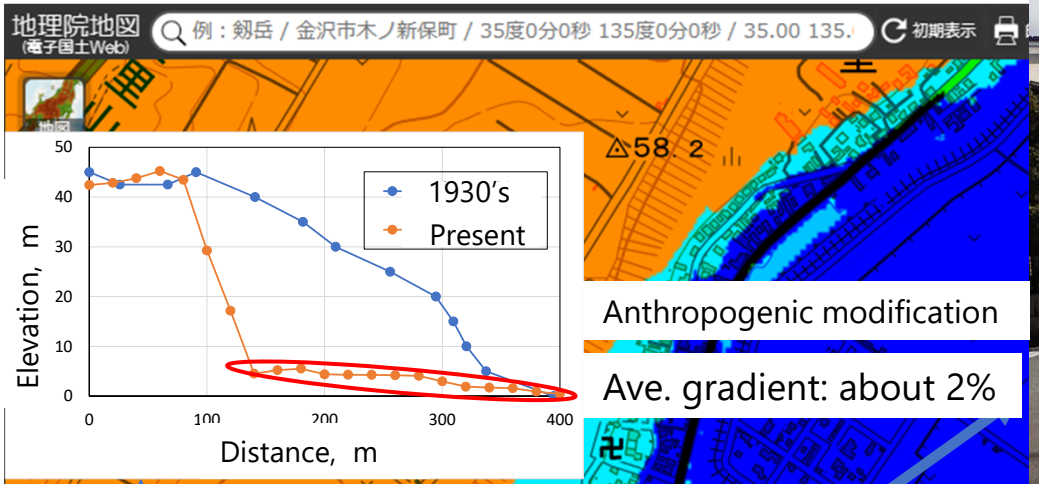
Fine sand

Shallow groundwater
Small SPT-*N*



Nishiaraya

Investigation:
6th Jan.: Prof. Yasuda and Prof. Ishikawa (Tokyo Denki Univ.)
3rd Feb.: Prof. Yasuda; Toyota and Takada (Nagaoka Univ. of Tech.)



Anthropogenic modification

Ave. gradient: about 2%

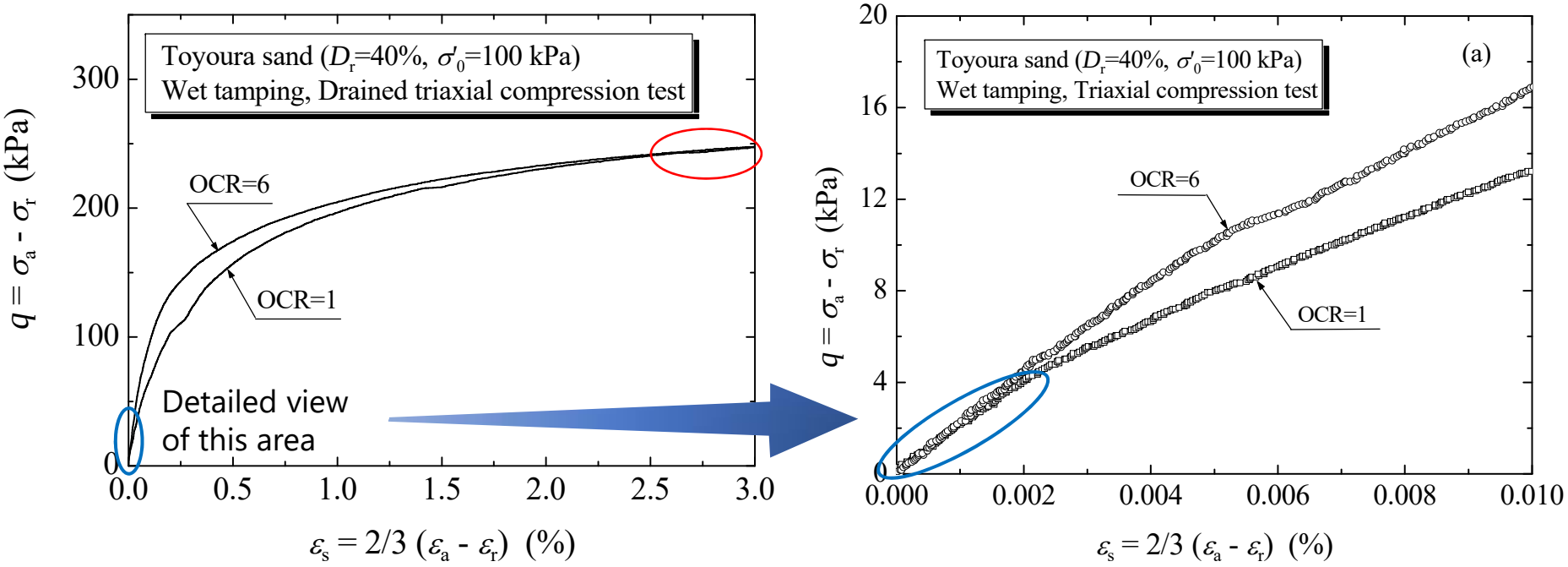
Extending flat ground

3rd Feb.

How much effects of pre-loading on liquefaction?

- Blue (lower than 2 m): No liquefied area (mainly soft clay in lagoon)
- Light blue (2 - 5.5 m): Damaged area by lateral flow
- Orange (higher than 5.5 m): No liquefied area (deeper groundwater level)

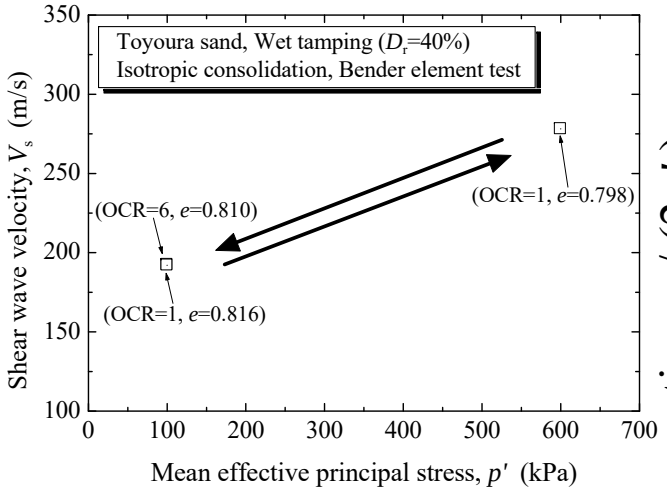
Effects of pre-loading (OCR) on stress-strain



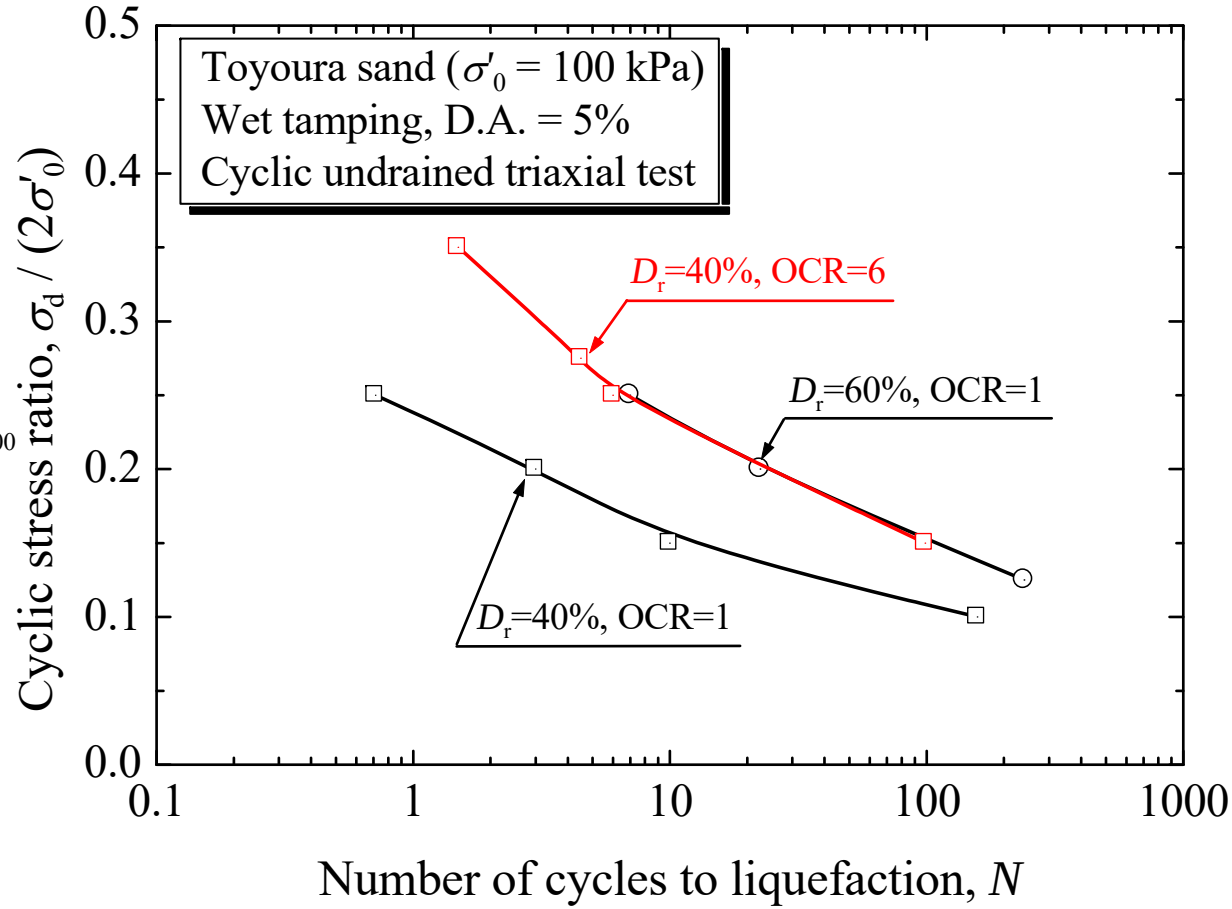
Very small strain: Slight effects of OCR
Medium strain: OCR effects are apparent
Large strain: OCR effects fade away

Reference DOI: 10.1139/cgj-2018-0575

Effects of pre-loading (OCR) on liquefaction



Slight effects of OCR on void ratio and V_s



CRR shows the increase effect of 20% relative density by loading of OCR=6.

Reference DOI: 10.1061/(ASCE)GT.1943-5606.0001634

Nishiaraya

Complicated land modification

Nishiaraya

Damage in dune side of the road

Spring water: high groundwater

Lateral flow to the road

Investigation:
3rd Feb.: Prof. Yasuda (Tokyo Denki Univ.),
Toyota and Takada (Nagaoka Univ. of Tech.)

Muro

Damage in lagoon side of the road

Lateral flow to the lagoon

Investigation:
3rd Feb.: Prof. Yasuda (Tokyo Denki Univ.),
Toyota and Takada (Nagaoka Univ. of Tech.)

Shaded relief map

Damage inside the cutting dune

Investigation: 3rd Feb.

Ohsaki

Pref. road

Expanding damage in flat ground

Muro

About 160 m inside from the road

Nishiaraya

Tsurugaoka

East side of the road: Farm land in 1960's.

Serious liquefaction damage

13th Mar.

Pref. road

13th Mar.

3rd Feb.

Lateral flow to the road

Lateral flow parallel to the road

1 m-contour
Ejected sand
Subsidence
Uplift
Ditch damage

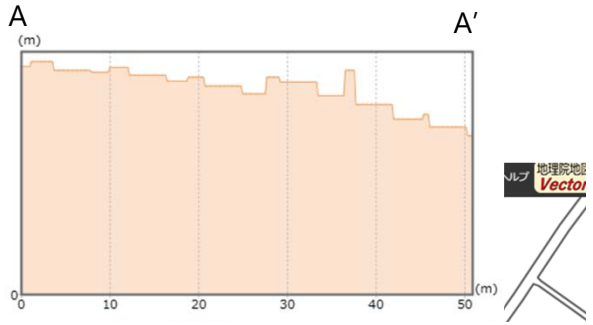
0 50 100 m

Tsurugaoka

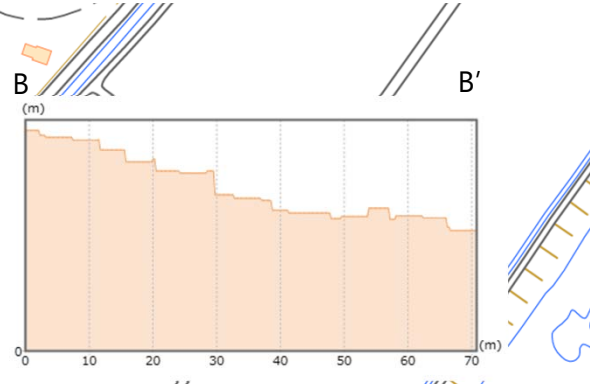
Investigation: 13th Mar.

1 m-contour

The contour falls into the road



Ave. gradient: about 1.3%



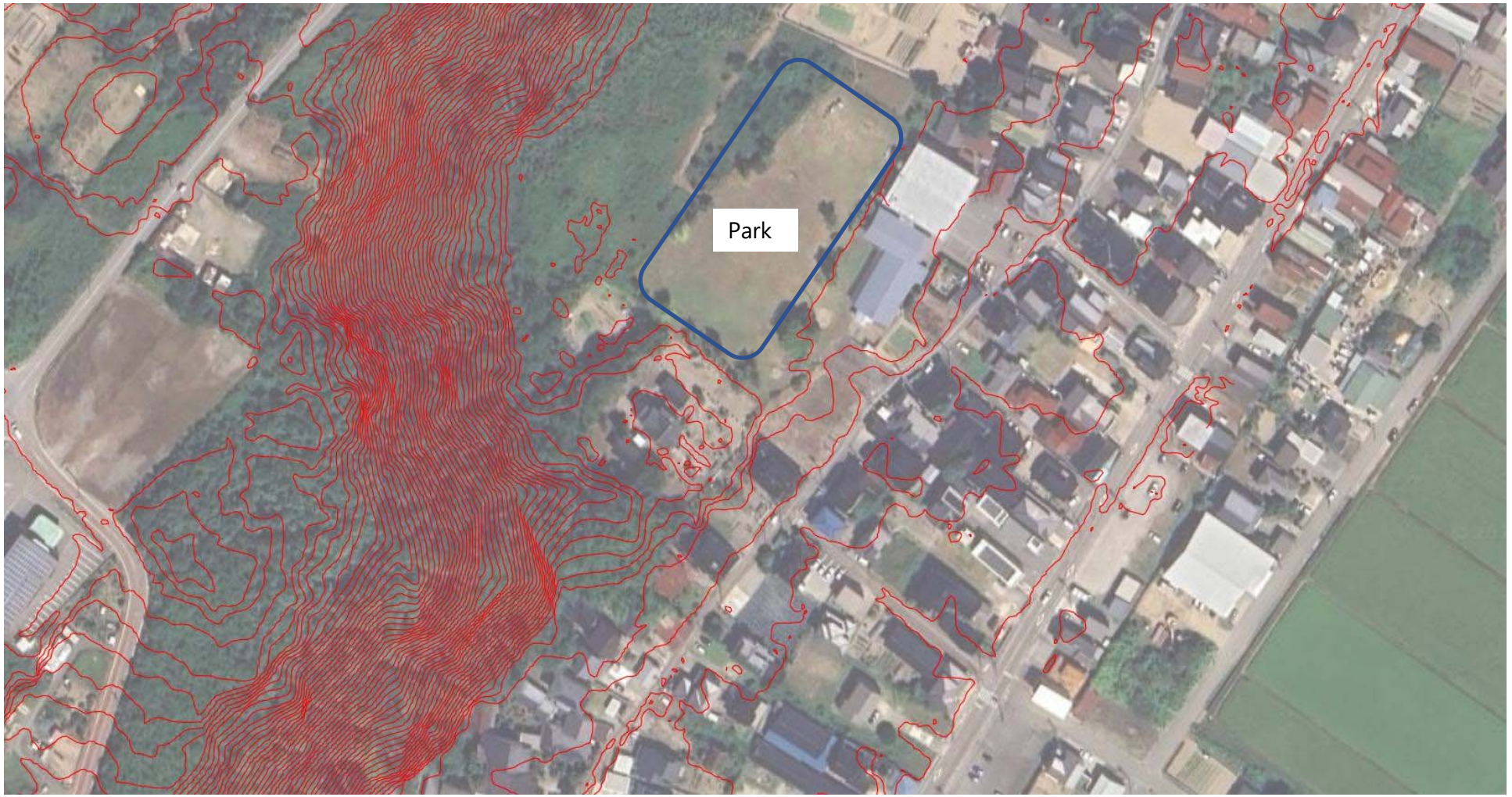
Ave. gradient: about 2%

GSI: Web maps

Nishiaraya

As a next step, amount of lateral flow should be measured quantitatively.

1 m-contour



The park was almost flat before the earthquake.

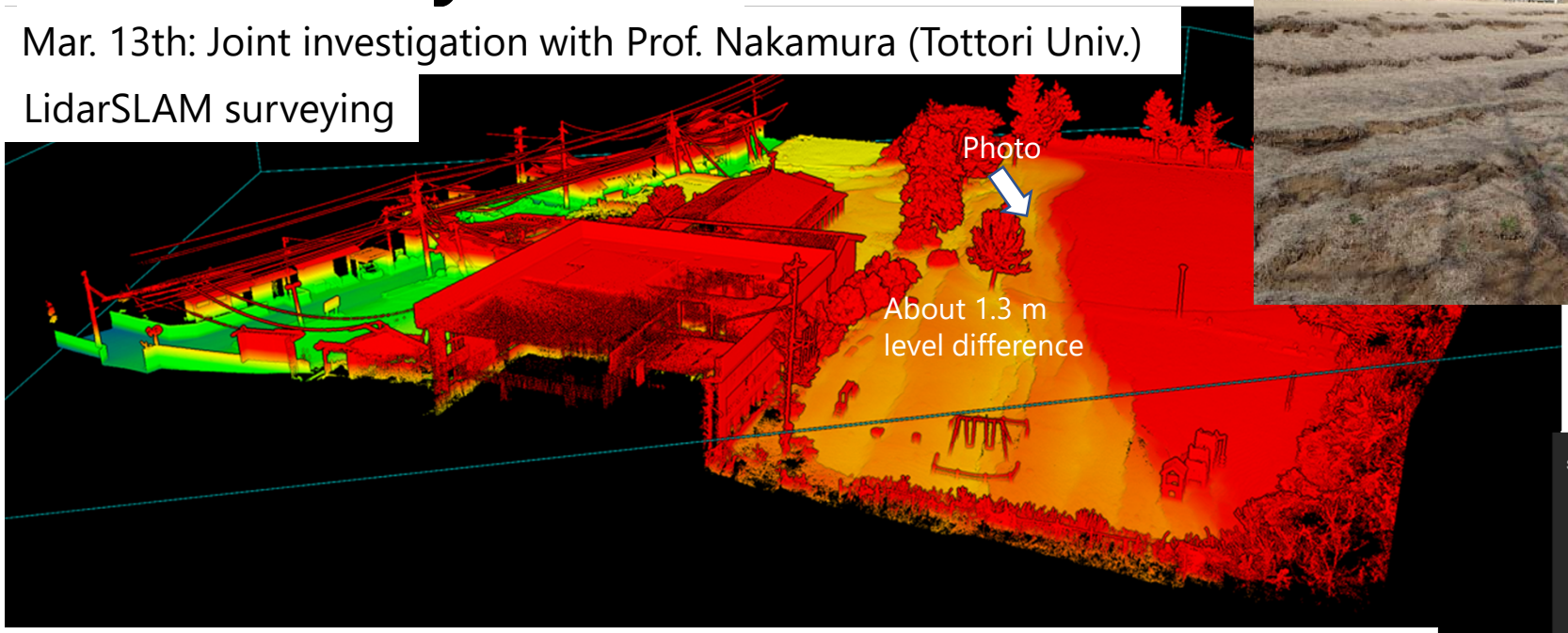
Nishiaraya

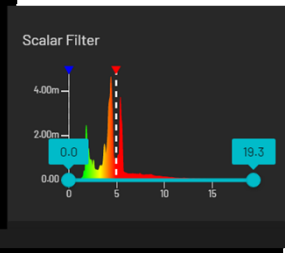
Nishiaraya park

3rd Feb.

Mar. 13th: Joint investigation with Prof. Nakamura (Tottori Univ.)

LidarSLAM surveying



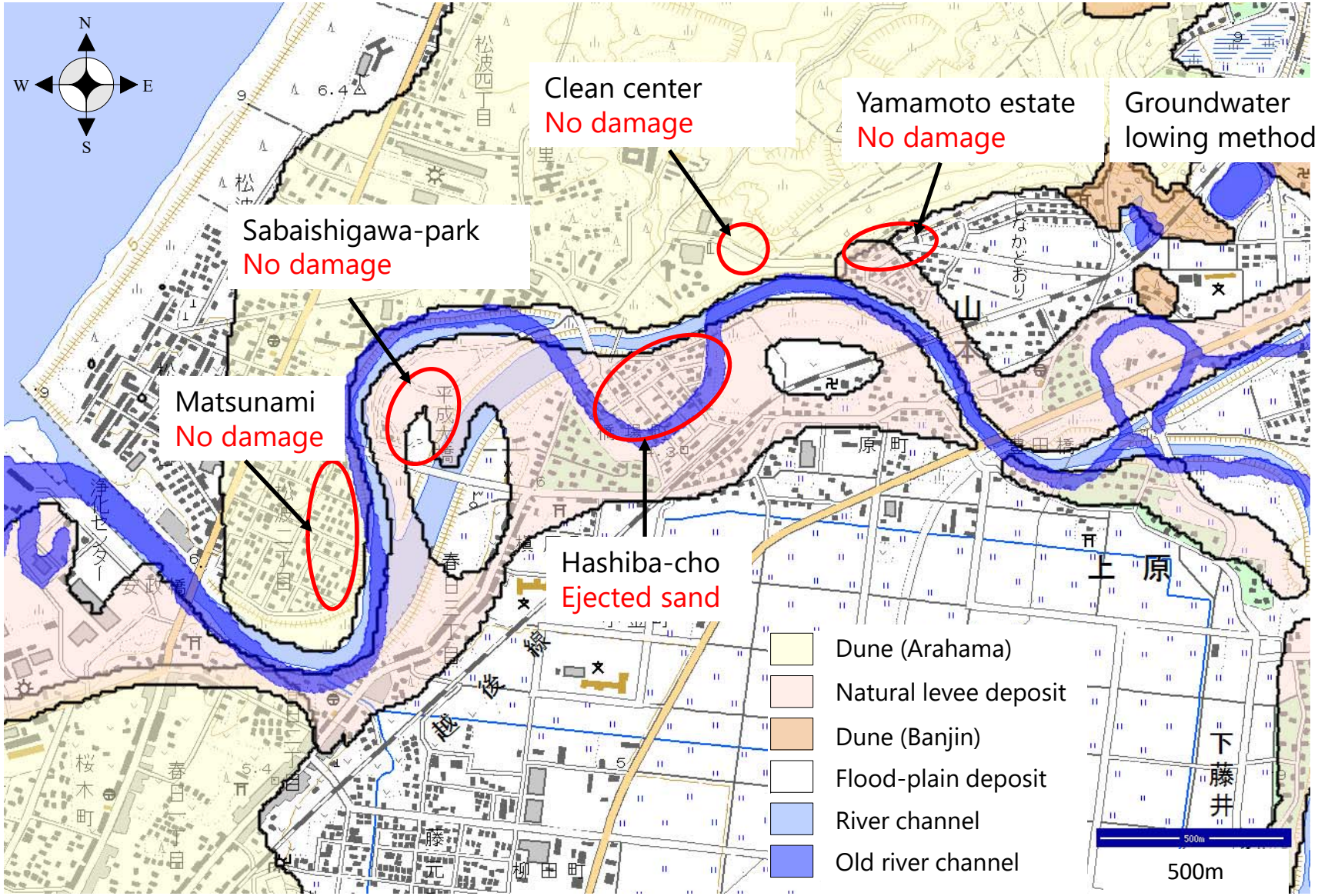


3rd Feb.

Other reliquefaction

- Severe liquefaction occurred in Kashiwazaki-city (along Sabaishi-river) during the 2007 Off Chuetsu Earthquake

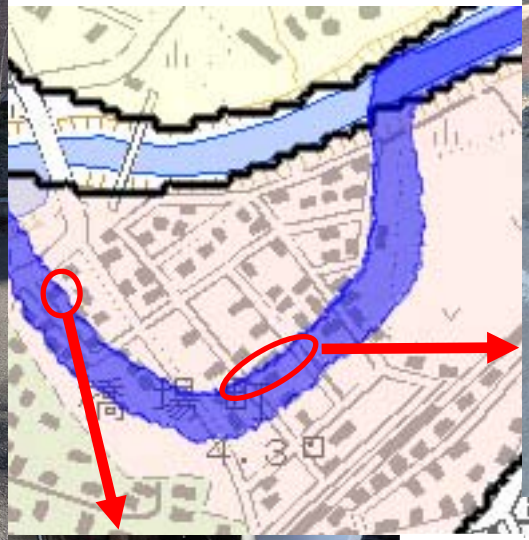
Kashiwazaki-city



AIST: GeomapNavi
GSI: Web maps

Kashiwazaki-city

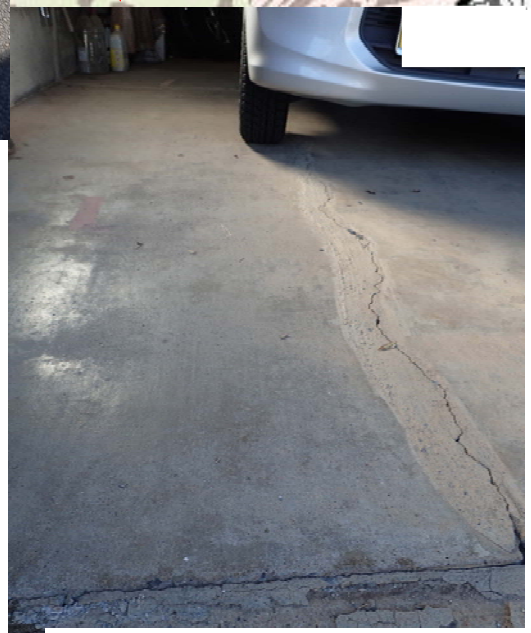
Investigation: 5th Jan.



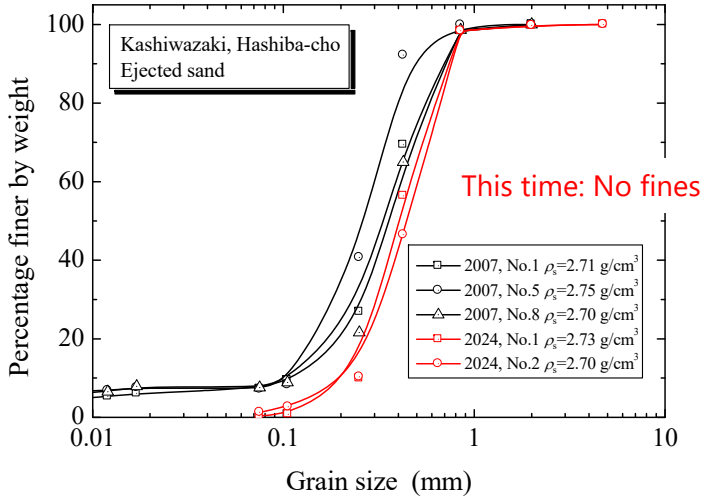
Ejected sand

Testimony: Sand was removed. A lot of water sprang out from the ground.

This place was liquefied at the 2004 Chuetsu and the 2007 Off Chuetsu Earthquakes



Expanding crack from 2007



Liquefaction scale was small: Only surface was liquefied.

Other reliquefaction

- There is liquefaction report (JGS) in Suzu-city (Nonoe, Ugai, and Shoin) during the 1993 Off Noto Peninsula Earthquake

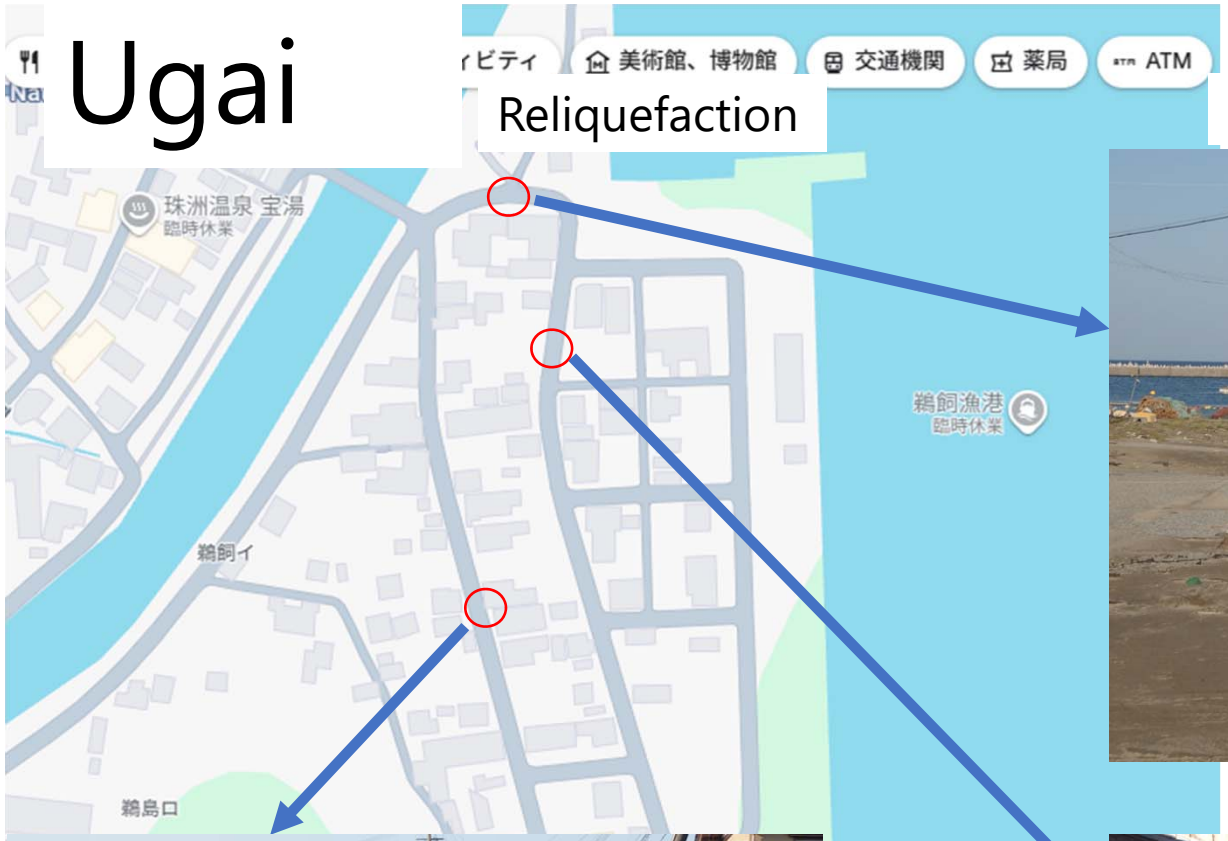
Nonoe

Reliquefaction

Investigation: 2nd Feb.

Ugai

Reliquefaction



Investigation: 14th Mar.

Google Map

Tsunami also hit this area

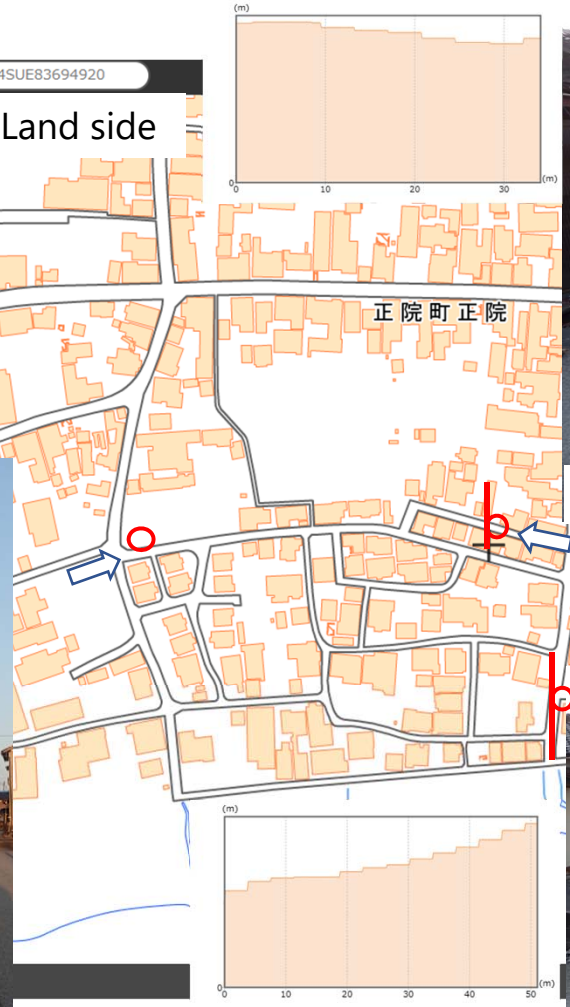
Shoin

Reliquefaction

Investigation: 14th Mar.

GSI: Web maps

AIST: Coastal dune deposit



Ejected sand was reported during the 2007 Noto Peninsula Earthquake

Lateral flow to the land side

Ave. gradient: 2% to land side

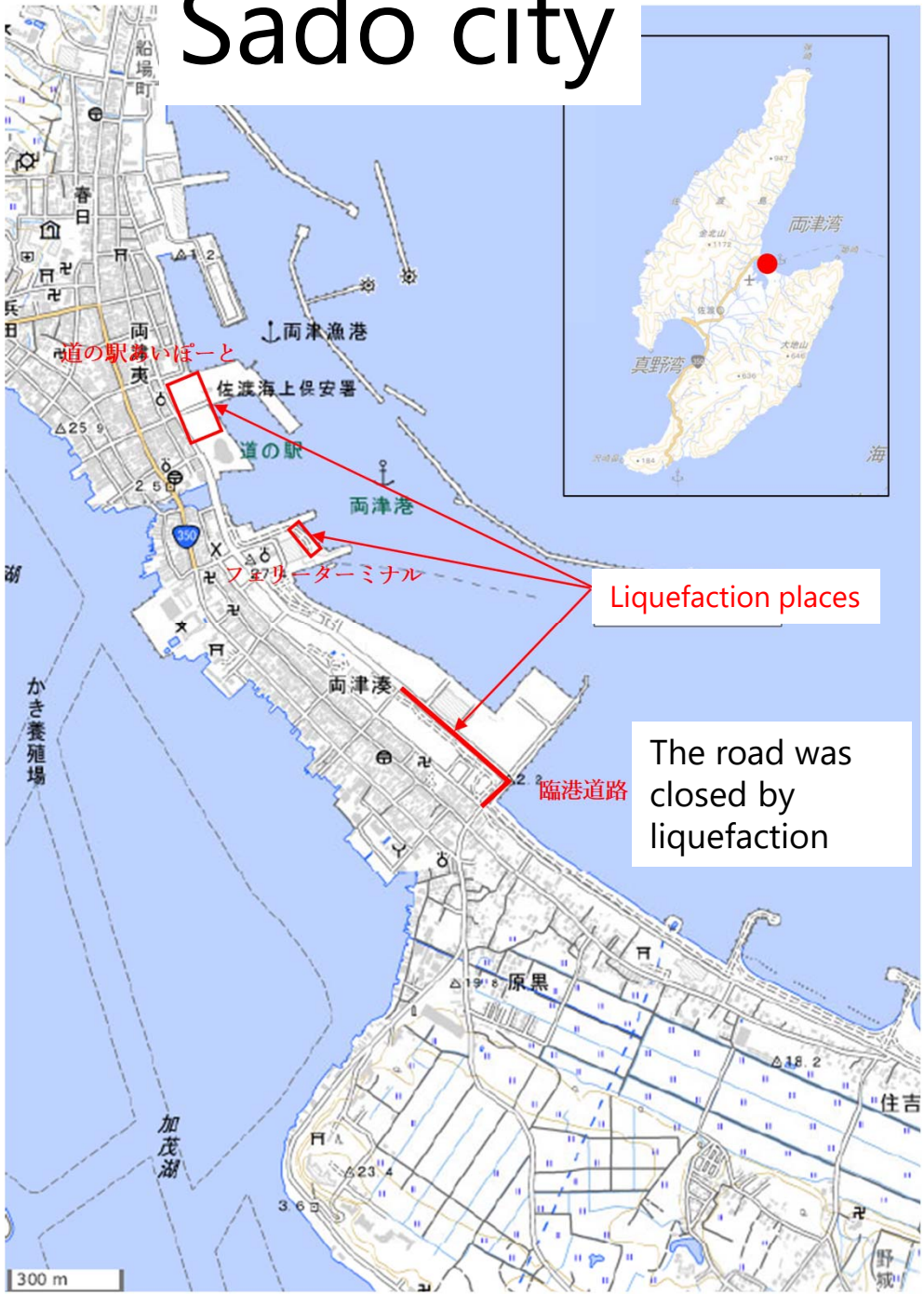
Ave. gradient: 3% to sea side

Leaning manhole to the sea side

Liquefaction in other sand dune deposits

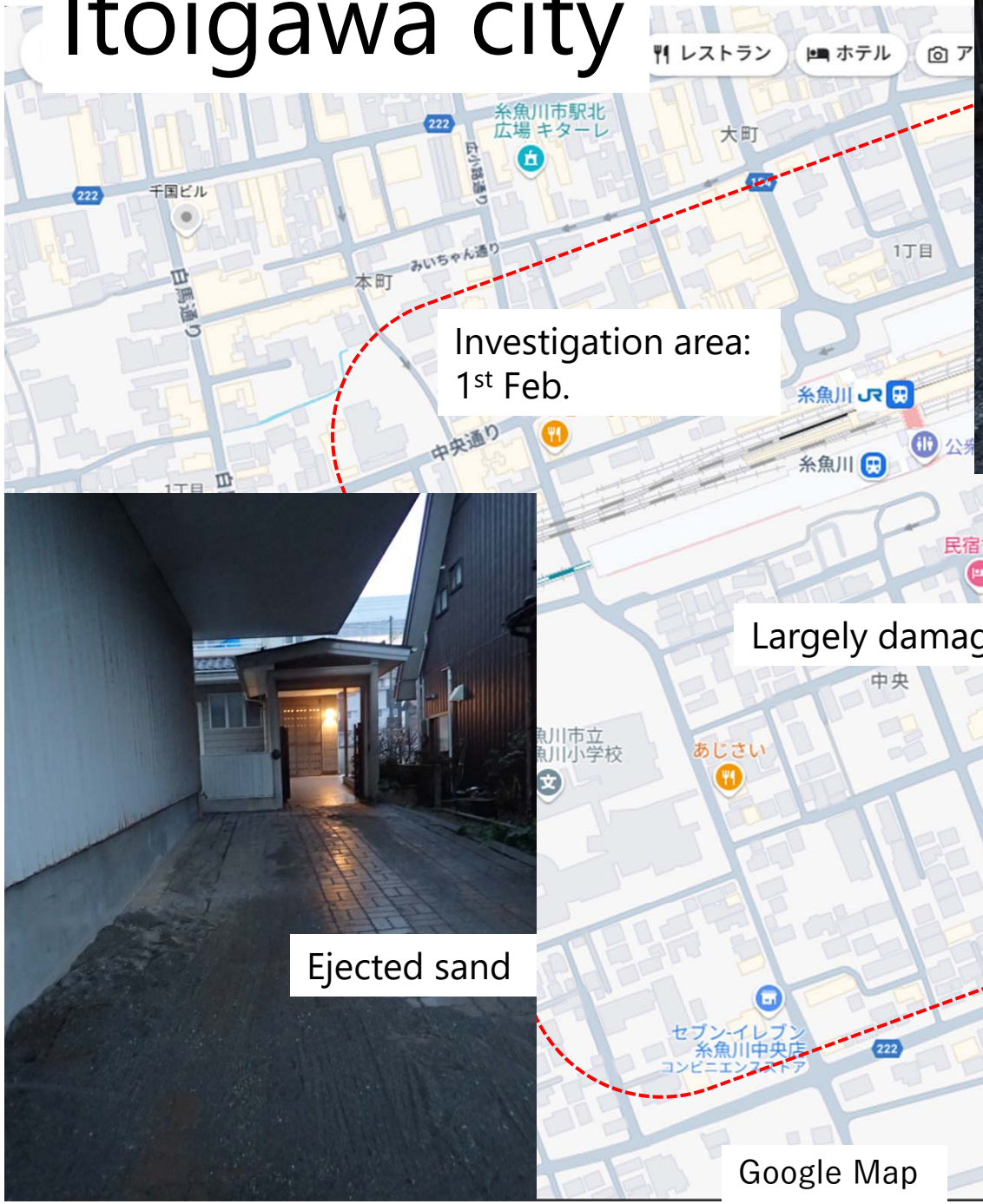
- In the case of loose and shallow groundwater

Sado city



11th Jan.
Mr. Taguchi (Fudo Tetra Corporation)

Itoigawa city



Inclined slab

Ejected sand

Settlement of the house

Himi city

Investigation: 2nd Feb.

Large area in the map was liquefied.

Severe liquefaction damage on residential house

A lot of ejected sand in parking lot

Damaged river wall through 37 m

Investigation area

Other liquefaction areas

- Alluvial plain deposit or earth filling

Takaoka city

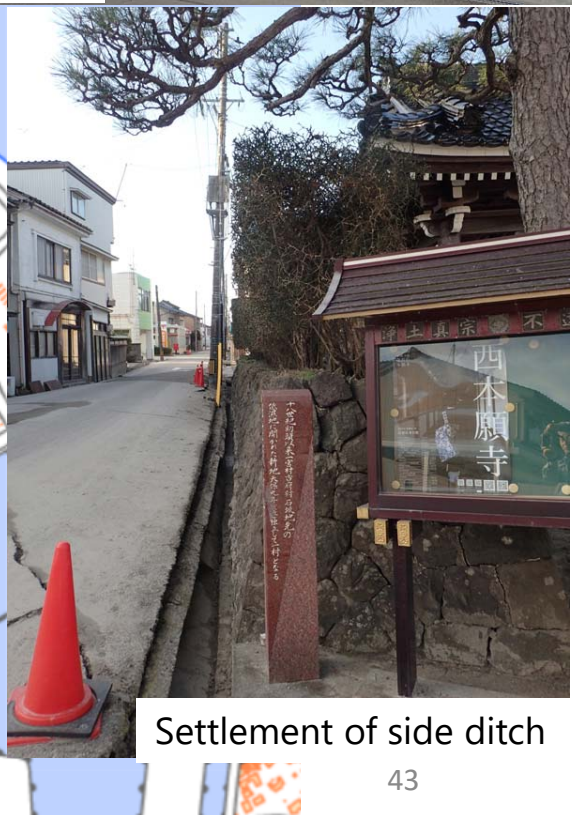
Investigation: 3rd Feb.
Prof. Yasuda (Tokyo Denki Univ.),
Toyota and Takada (Nagaoka Univ. of Tech.)

Leaning of house

Ejected sand

Liquefied area through the road

No liquefied area



Settlement of side ditch

Nanao city

Investigation: 2nd Feb.

Google Map

Wajima city

Investigation: 2nd Feb.

Original ground mainly consists of clay. Therefore, ejected sand might be generated from filling materials.

Leaning and settlement

Google Map

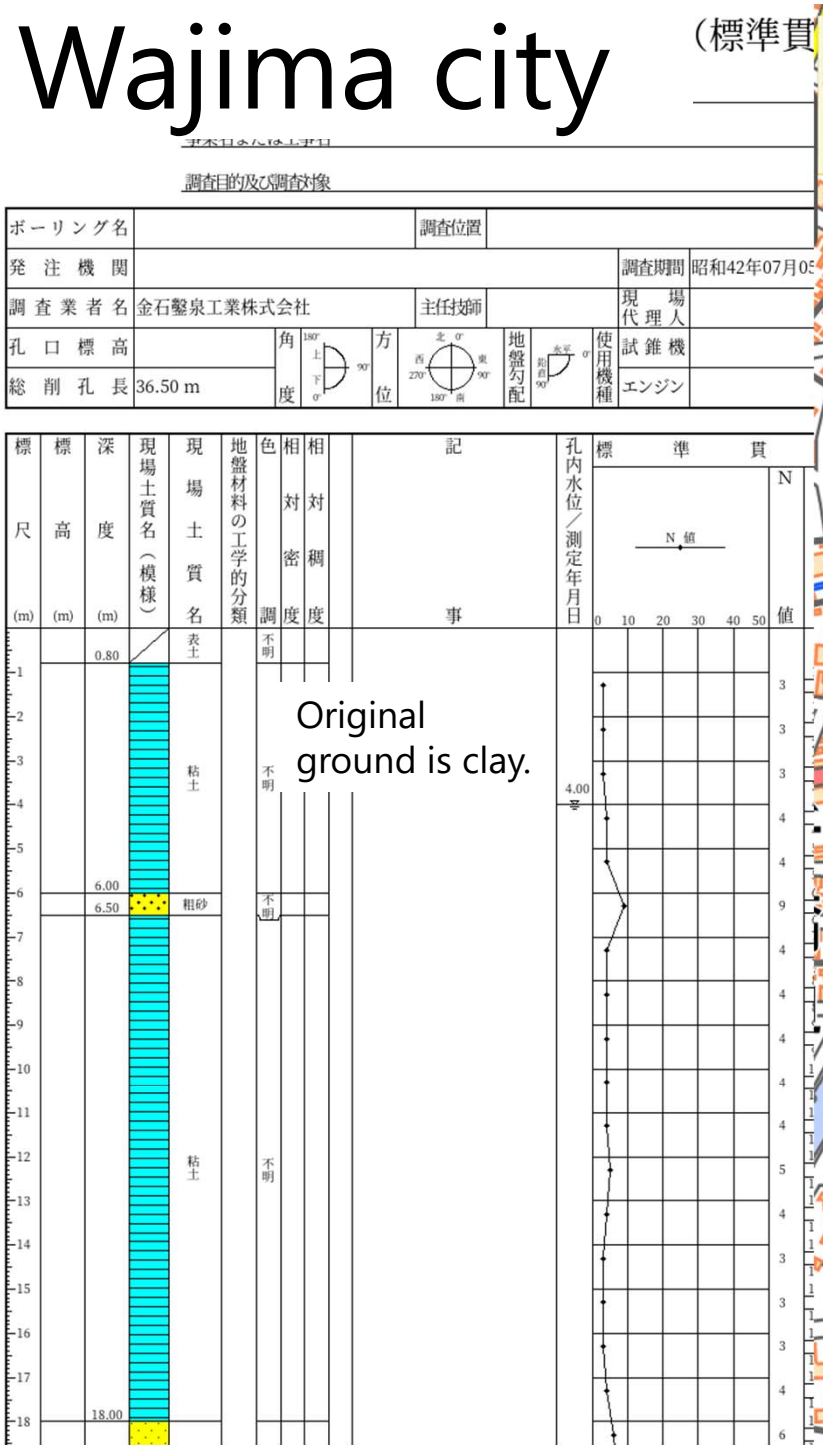
Ejected sand

Ejected sand

Ejected sand

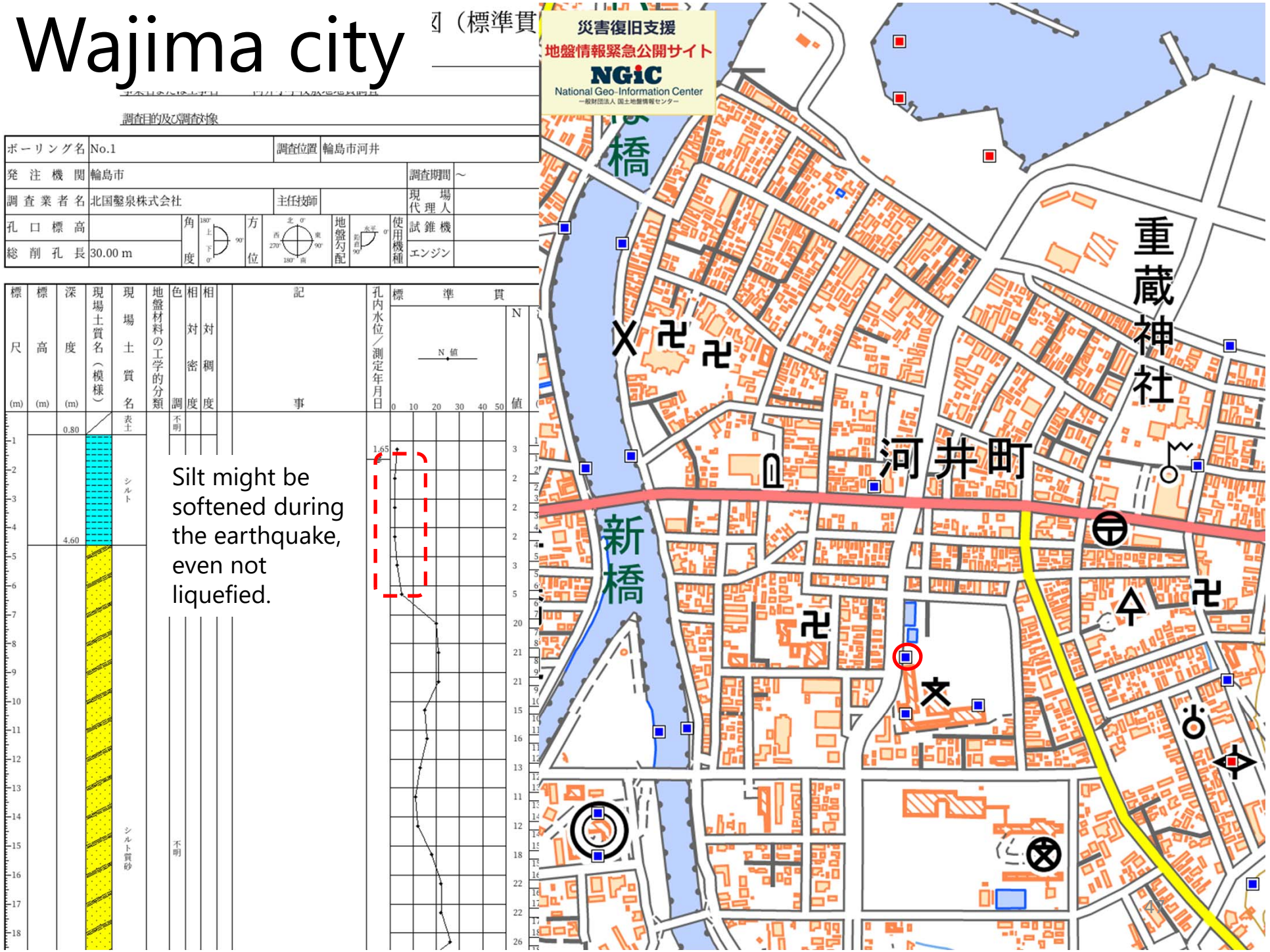
Uplift of manhole

Wajima city



Original ground is clay.

Wajima city


（標準貫
調査目的及び調査対象
ボーリング名 No.1
調査位置 輪島市河井
発注機関 輪島市
調査期間 ～
調査業者名 北国鑿泉株式会社
主任技師
現場代理人
孔口標高
総削孔長 30.00 m
角度
方位
地盤勾配
使用機種
試錐機
エンジン
標尺 (m)
標高 (m)
深度 (m)
現場土質名（模様）
現場土質名
地盤材料の工学的分類
色調
相対密度
相対稠度
記事
孔内水位／測定年月日
標準貫入試験 N値
N値
0.80
4.60
表土
シルト
シルト質砂
不明
1.65
Silt might be softened during the earthquake, even not liquefied.
災害復旧支援
地盤情報緊急公開サイト
NGiC
National Geo-Information Center
一般財団法人 国土地盤情報センター
橋
新橋
河井町
重蔵神社

Liquefaction in lagoon

- Soft clayey soils and high groundwater: when sand exists, the damage is extended by liquefaction.

Hakui city (Ouchi lagoon)

28th Feb.
Prof. Shinbo (NIT-Ishikawa)

Google Map

Kahoku-gun (Kahoku lagoon)

8th Jan.
Mr. Terasaki (Natural Consultant Co., Ltd.)

Level difference in levee and road

Google Map

Kaga city (Shibayama lagoon)

Ejected sand trace

Uneven road

15th Feb.
Prof. Takahara (Kanazawa Inst. of Tech.)
Prof. Shinbo (NIT-Ishikawa)

Google Map

Arawa city and Sakai city

Provided from Prof. Arai
(formerly, Fukui Univ.)

Effects of countermeasures against liquefaction

- Shinano-river, Yasuragi-tei (Niigata city)

Liquefaction trace during the 1964 Niigata Earthquake

Joint research with Prof. Kazama (Tohoku Univ.)

Geoslicer

GS-2 (GL -5.0 to -6.3 m)

Original image

Adjusted color tone

1.3 m

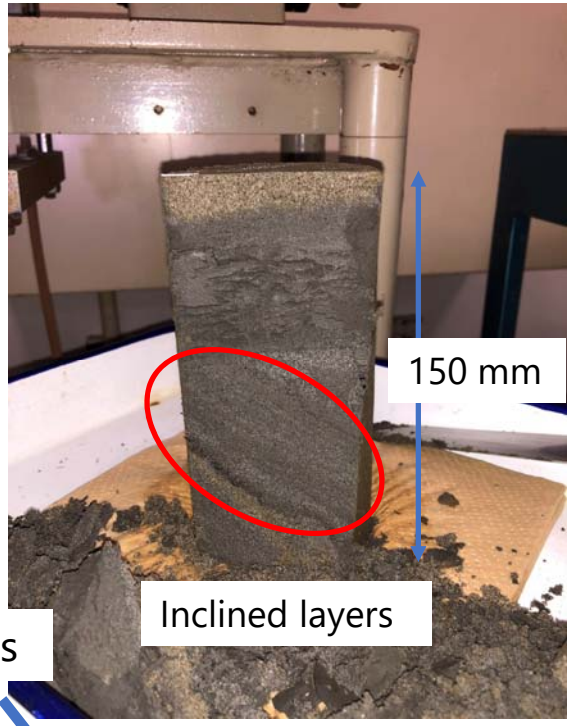
Age determination: 1717 – 1949

Clay, Silt

Sand

GS Sampling

G.L. -5.0 to -7.0 m

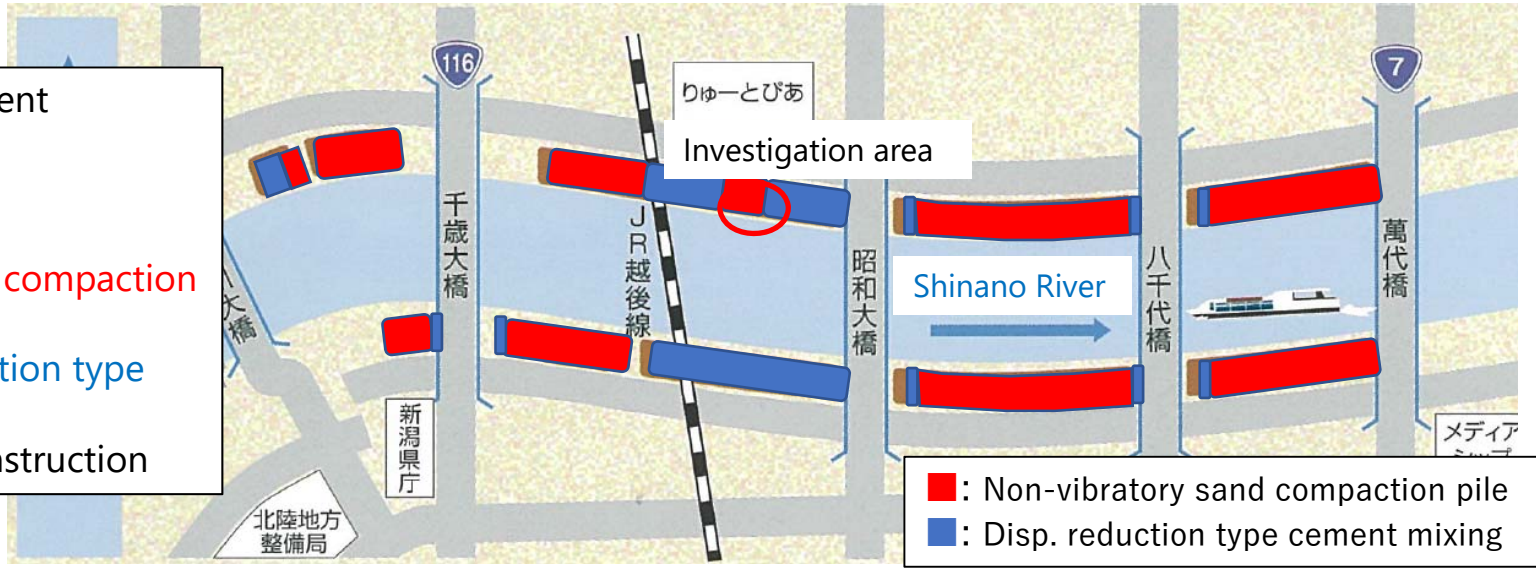


Drainage ditches

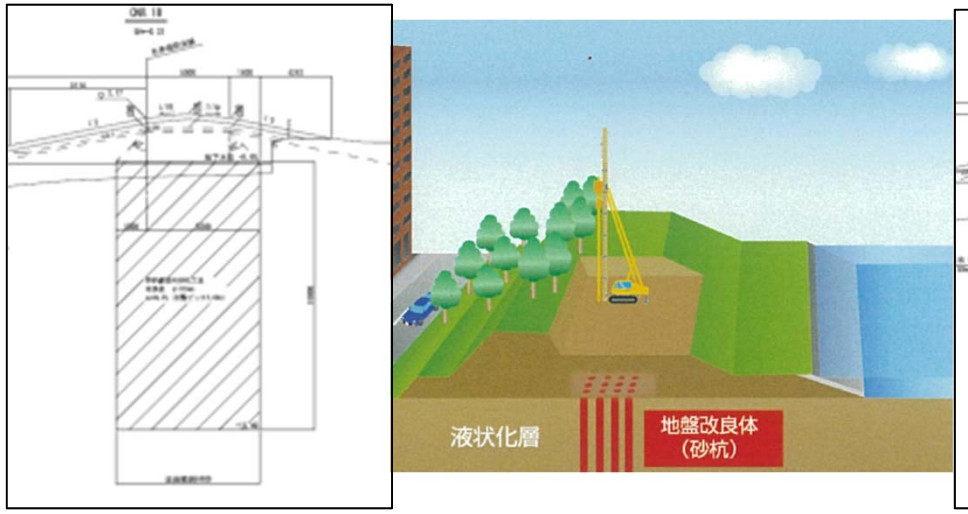
Deeper layer than 5 m was also liquefied during the 1964 Niigata Earthquake.

Measures against liquefaction (Yasuragi-tei)

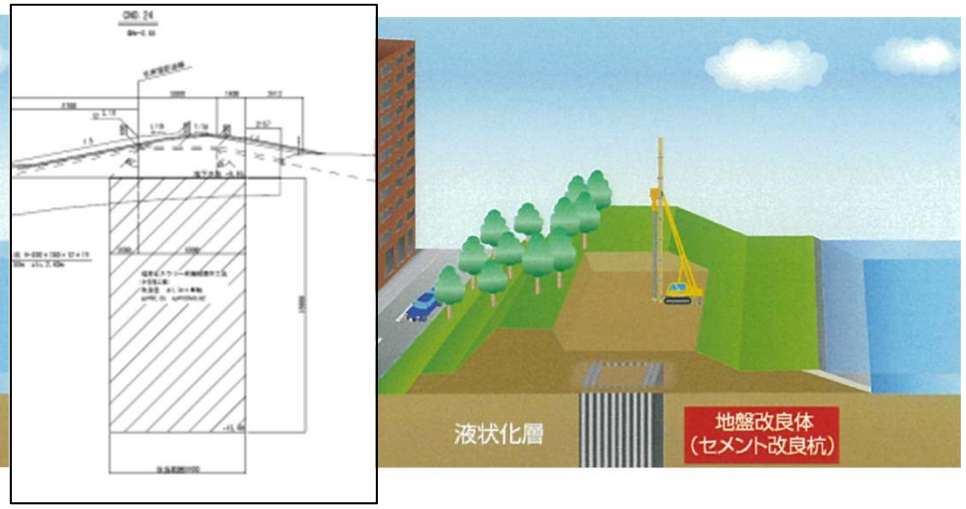
■Range of improvement
Width: 8 – 9 m
Depth: 9 – 20 m
■Methods
Non-vibratory sand compaction pile
Displacement reduction type cement mixing
for neighboring construction



(Non-vibratory sand compaction pile)



(Displacement reduction type cement mixing)



Riverbed: Sheet piles (depth: 10 – 13 m) with tie rod

Summary

- Wide range of liquefied areas (from Fukui to Niigata): Strong seismic motion propagated extensively along the coastline

- Liquefied area: End region of sand dune, Old river channel, Plain deposit, Earth filling, and Lagoon

  Terrain modification should be concern.

- Reliquefaction: 1891 Nobi, 1964 Niigata, 1993 Off Noto Peninsula, 2004 Chuetsu, 2007 Off Chuetsu, and 2007 Noto Peninsula Earthquakes

- Lateral flow: End region of sand dune, and Gentle slopes

  Liquefied ground flows sensitively to the slope direction