Site characterization for geotechnical hazards associated with soil liquefaction prevailing in Kanto region based on geotechnical field investigations

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(1) Objectives

To carry out field investigations & to disclose geotechnical soil profiles responsible for widely spread damages to infrastructures and private houses in Kanto region.

(2) Places that we visited for field investigations

- mainly downstream areas of Tonegawa river

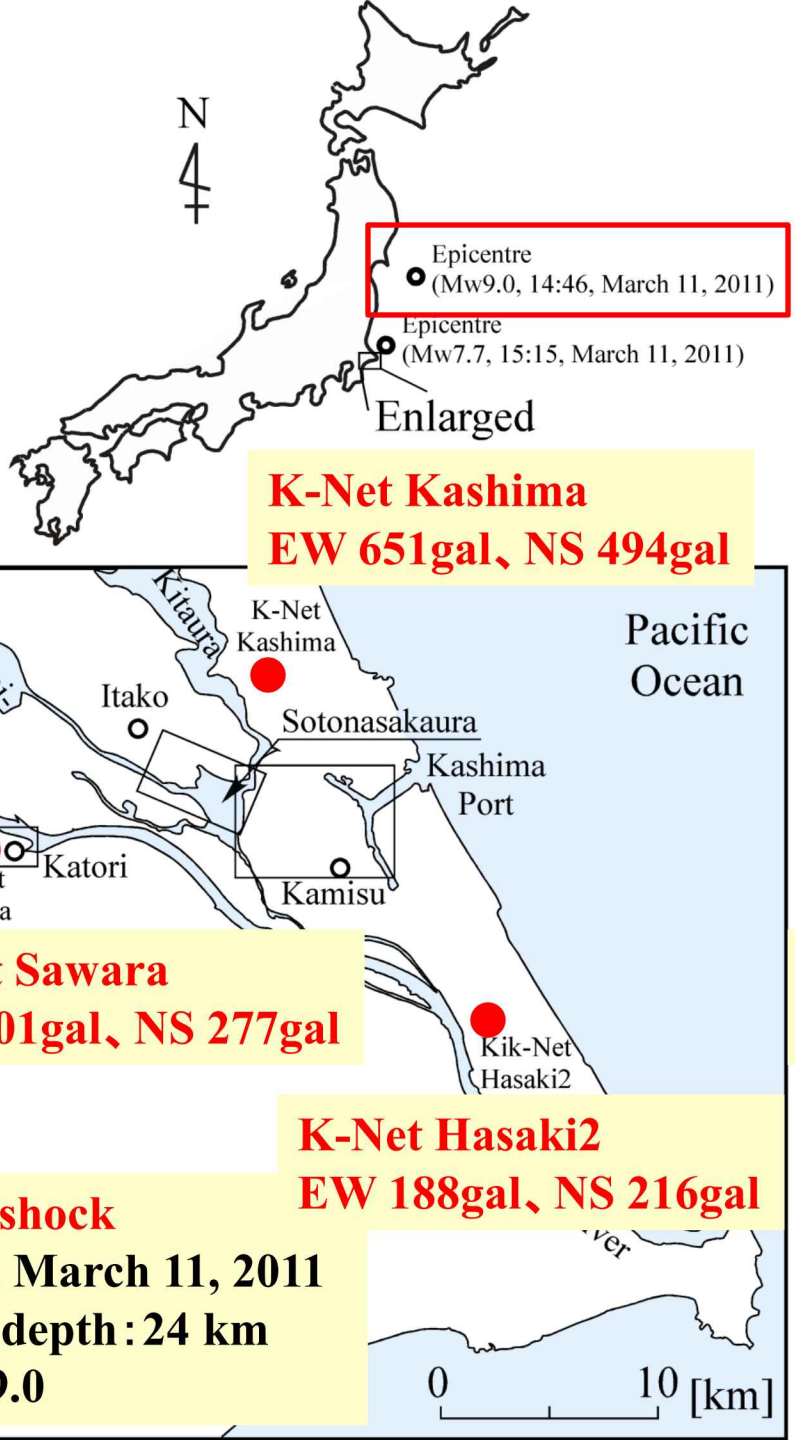
Place	Date
Sawara, Katori city, Chiba	**August 4 & 5, 2011**
Hinode, Itako city, Ibaraki	**September 8 & 9, 2011**
Fukashiba, Kamisu city, Ibaraki	**October 14 ~ 16, 2011**
Nakaminato, Hitachinaka city, Ibaraki	June 1 ~ 3, 2012
Gohno-ike pond, Kamisu city, Ibaraki	**November 21 ~ 23, 2012**
(Hinode, Urayasu city, Chiba)	September 20 & 21, 2011

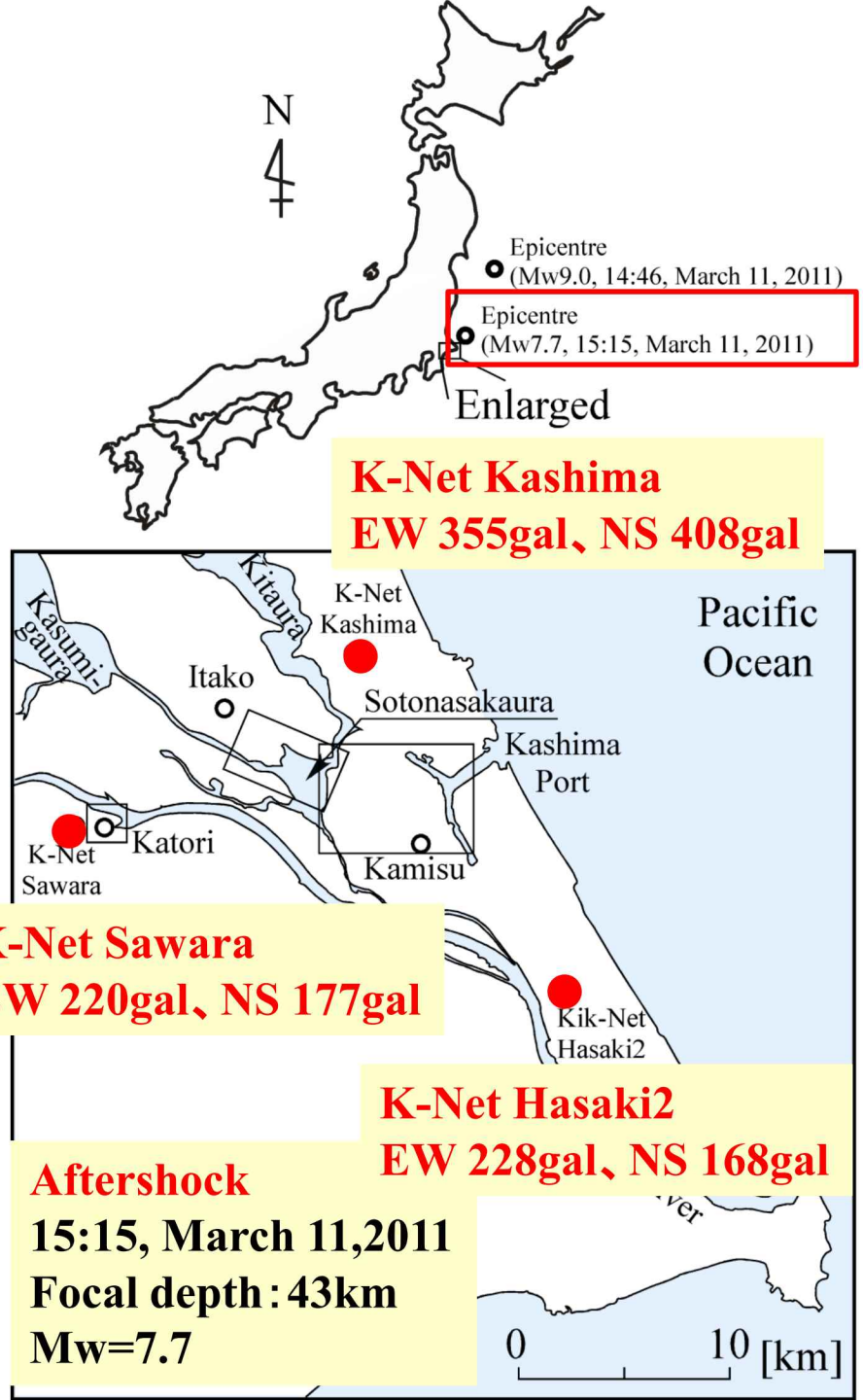
(3) Geotechnical issues

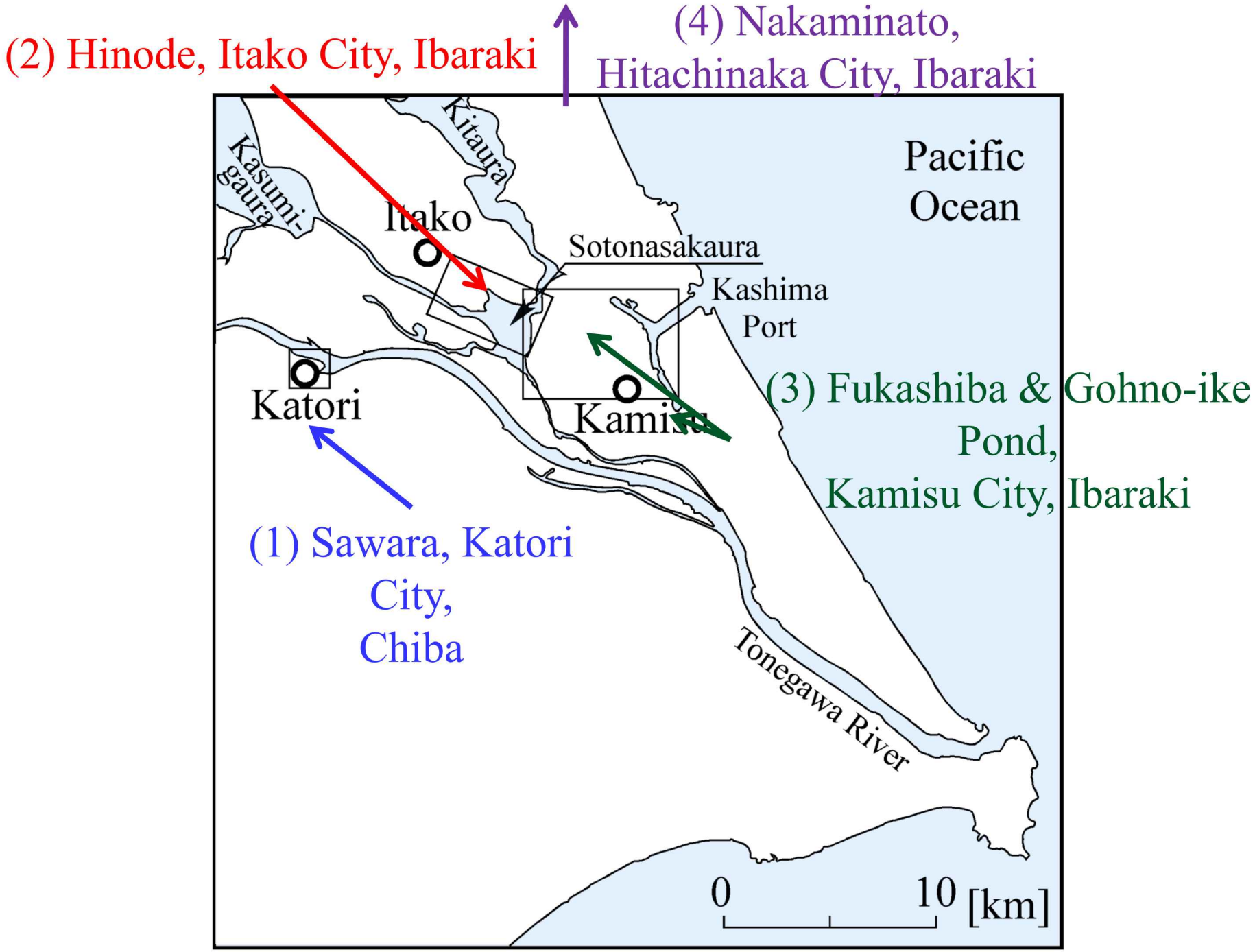
soil liquefaction during mega/huge earthquakes

especially,
(a) Effects of duration of mainshock & aftershocks

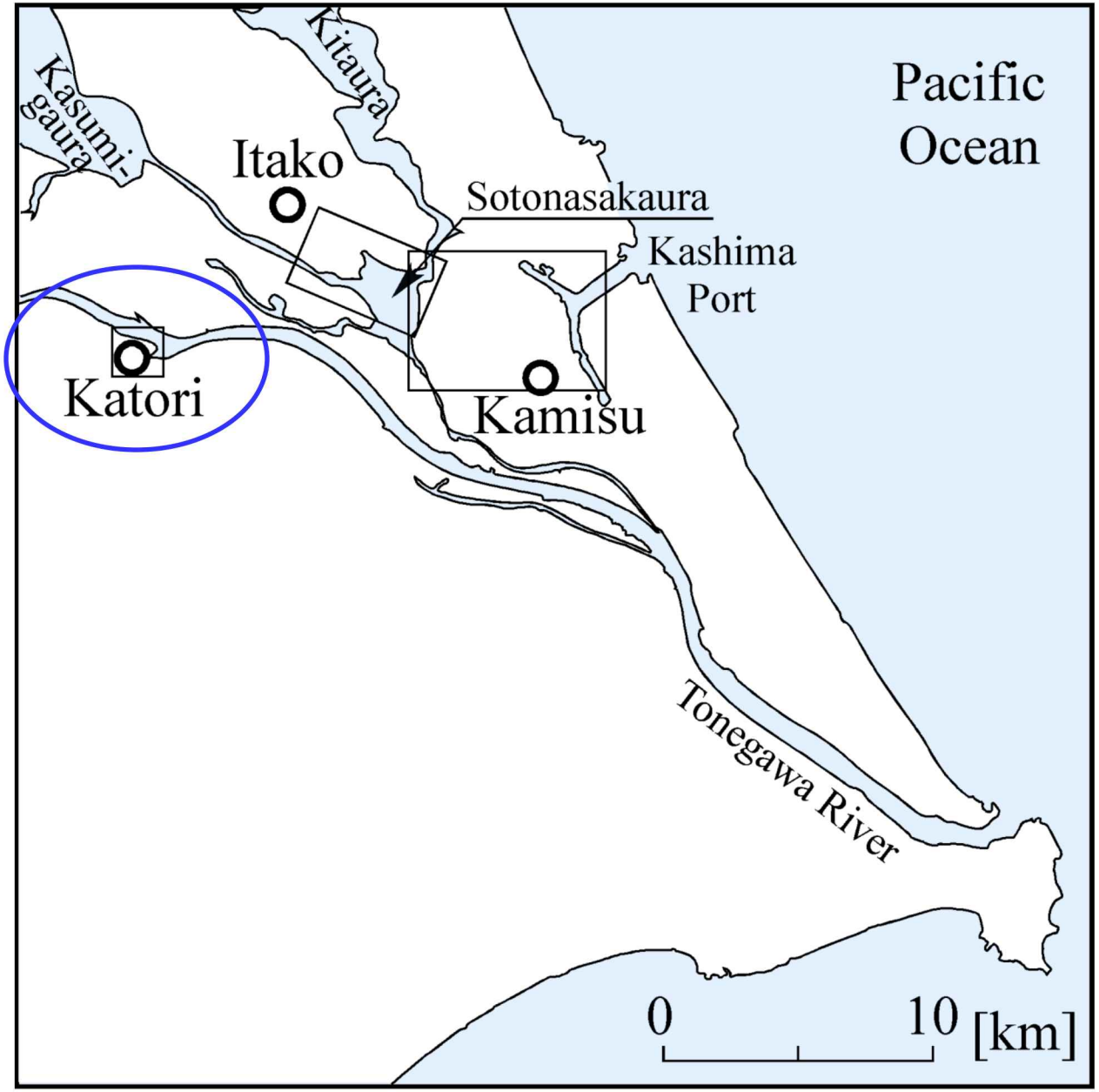
(b) Ageing effects & re-liquefaction of soils
(reclaimed soil deposits / natural soil deposits)
(how many years have passed since reclamation)

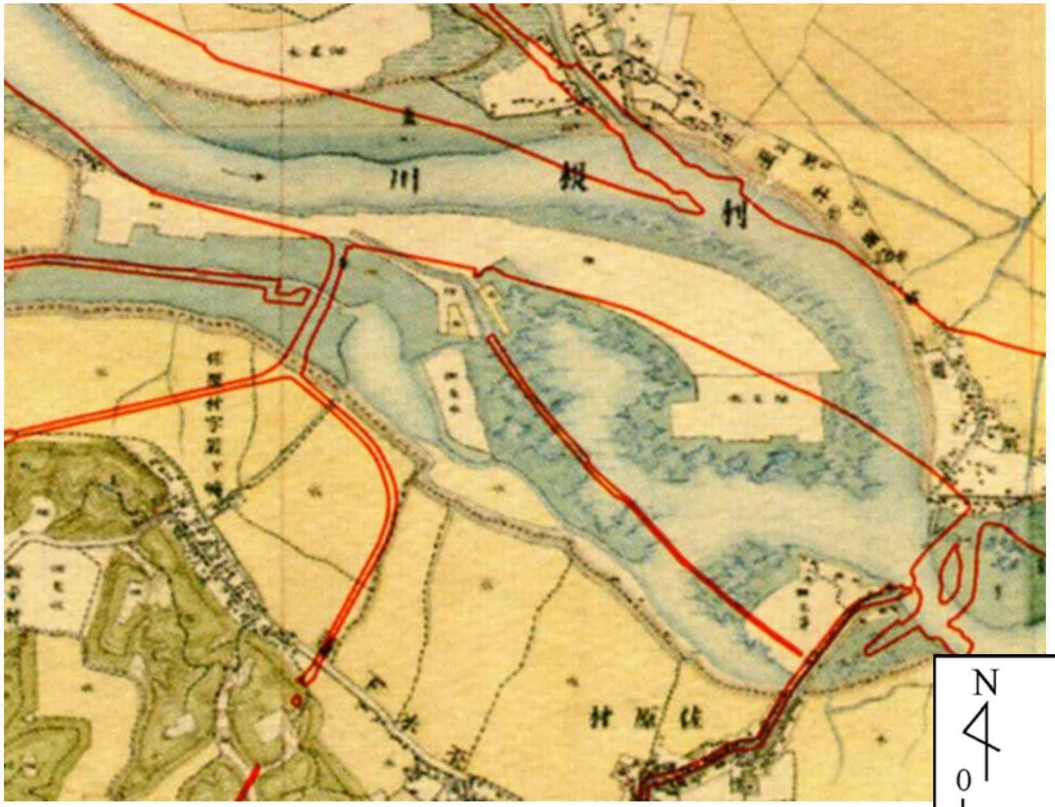

N
Epicentre
(Mw9.0, 14:46, March 11, 2011)
Epicentre
(Mw7.7, 15:15, March 11, 2011)
Enlarged
K-Net Kashima
EW 651gal、NS 494gal
Kitaura
Kasumi-gaura
K-Net
Kashima
Pacific
Ocean
Itako
Sotonasakaura
Kashima
Port
K-Net
Sawara
Katori
Kamisu
K-Net Sawara
EW 301gal、NS 277gal
Kik-Net
Hasaki2
K-Net Hasaki2
EW 188gal、NS 216gal
Main shock
14:46, March 11, 2011
Focal depth：24 km
Mw=9.0
0
10 [km]


N
Epicentre
(Mw9.0, 14:46, March 11, 2011)
Epicentre
(Mw7.7, 15:15, March 11, 2011)
Enlarged
K-Net Kashima
EW 355gal、NS 408gal
Kitaura
Kasumi-gaura
K-Net
Kashima
Pacific
Ocean
Itako
Sotonasakaura
Kashima
Port
K-Net
Sawara
Katori
Kamisu
K-Net Sawara
EW 220gal、NS 177gal
Kik-Net
Hasaki2
K-Net Hasaki2
EW 228gal、NS 168gal
Aftershock
15:15, March 11,2011
Focal depth：43km
Mw=7.7
0
10 [km]


(2) Hinode, Itako City, Ibaraki
(4) Nakaminato, Hitachinaka City, Ibaraki
Kasumi-gaura
Kitaura
Pacific Ocean
Itako
Sotonasakaura
Kashima Port
Katori
Kamisu
(3) Fukashiba & Gohno-ike Pond, Kamisu City, Ibaraki
(1) Sawara, Katori City, Chiba
Tonegawa River
0
10 [km]

(1) Sawara, Katori City, Chiba

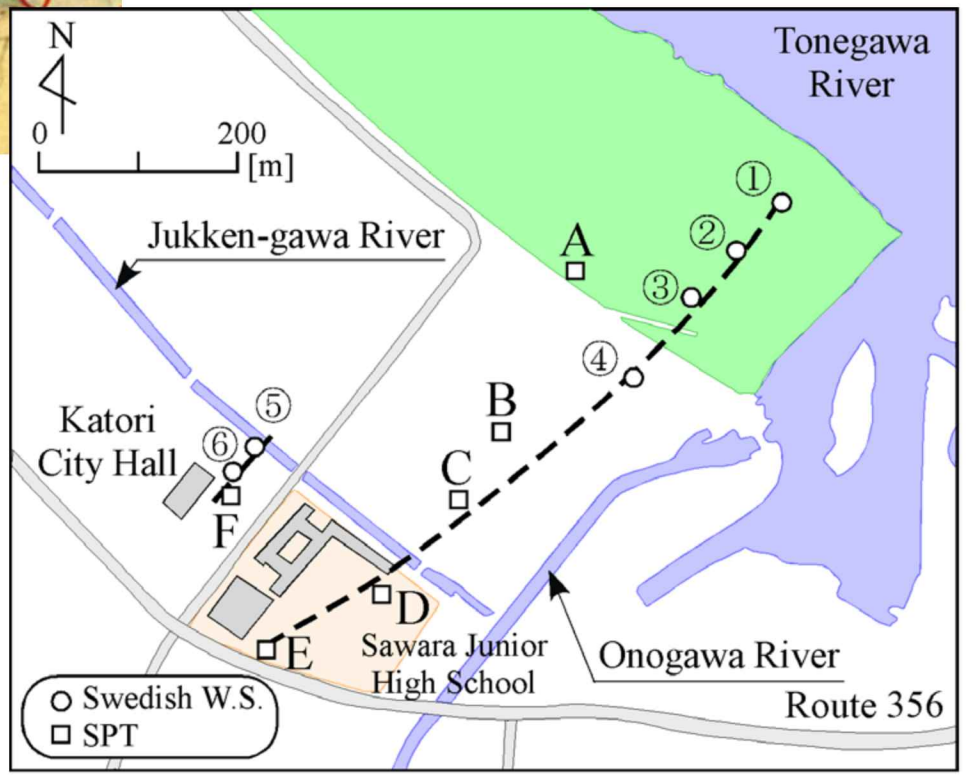




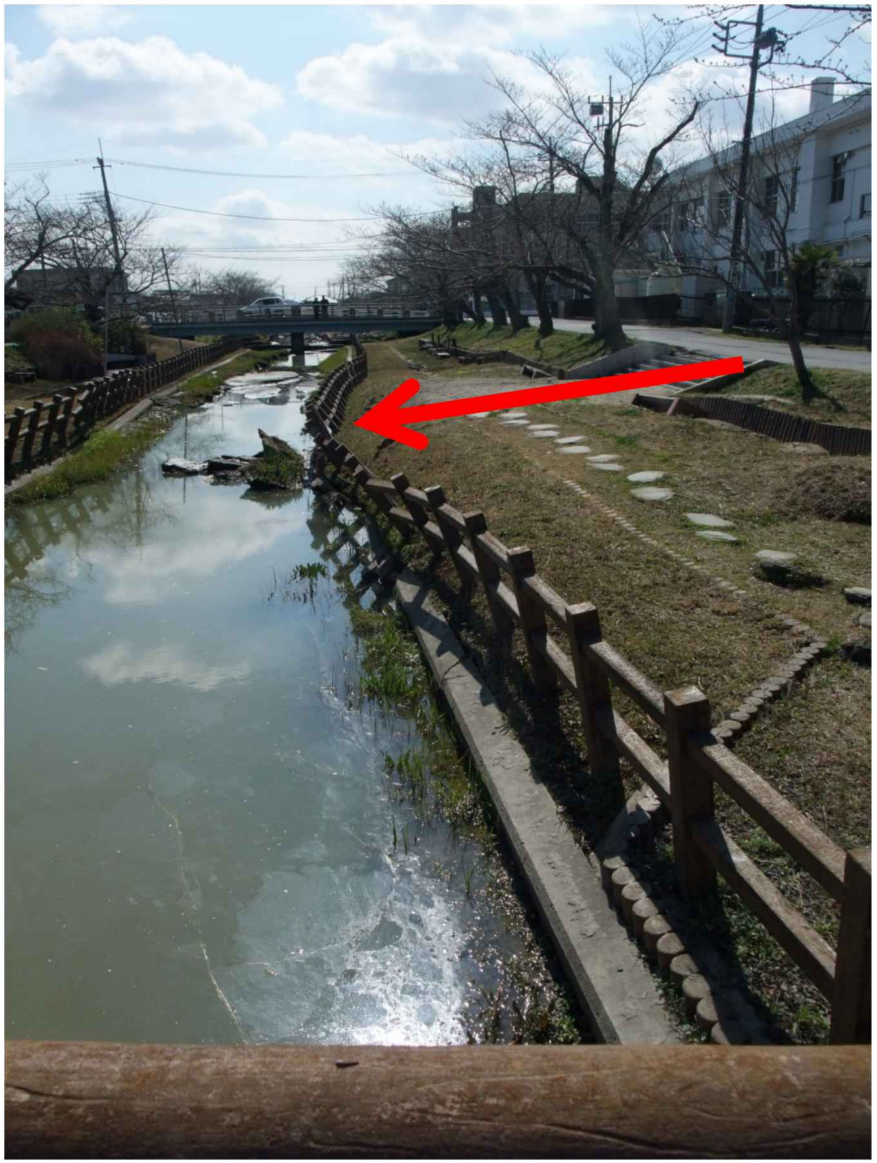
(after Tonegawa River Downstream Office 2011)

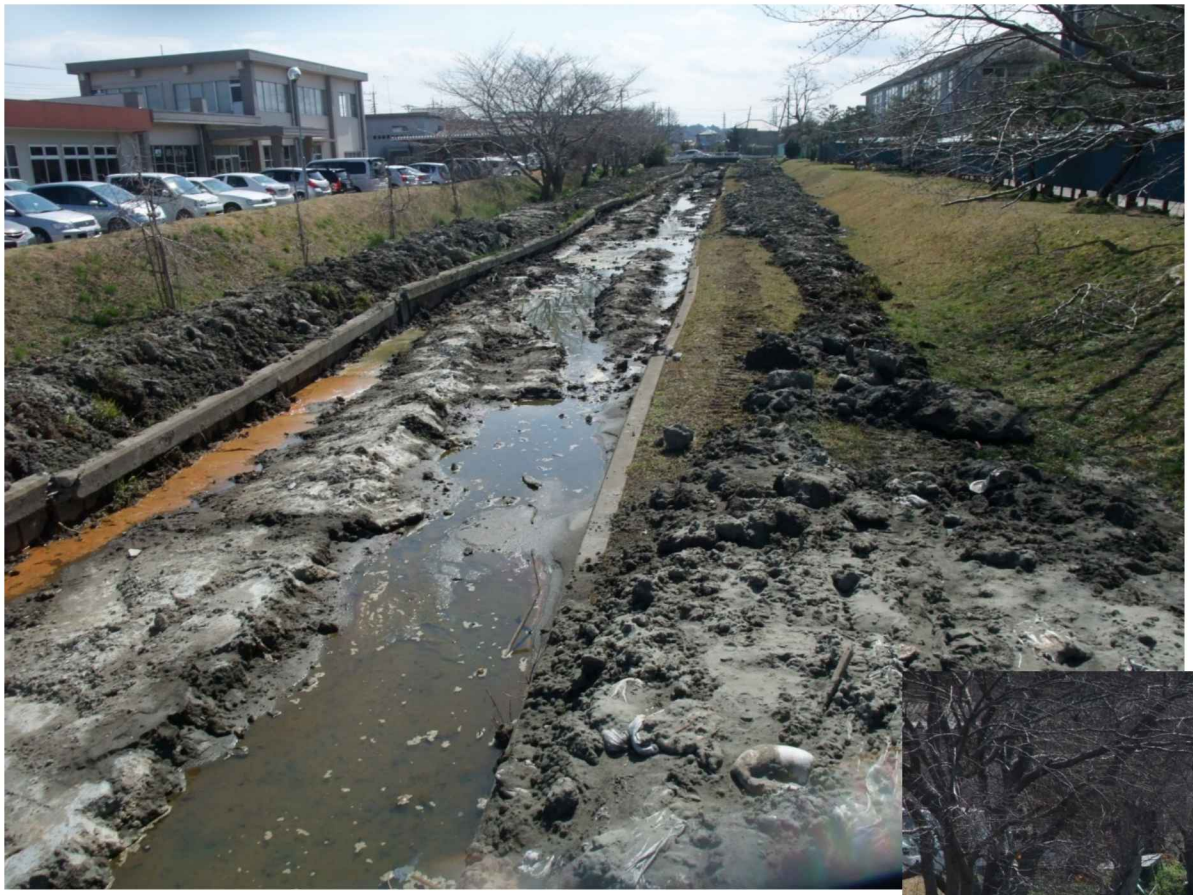
Old map of 1880's

The red lines indicate the current water side line.



Jukkengawa River





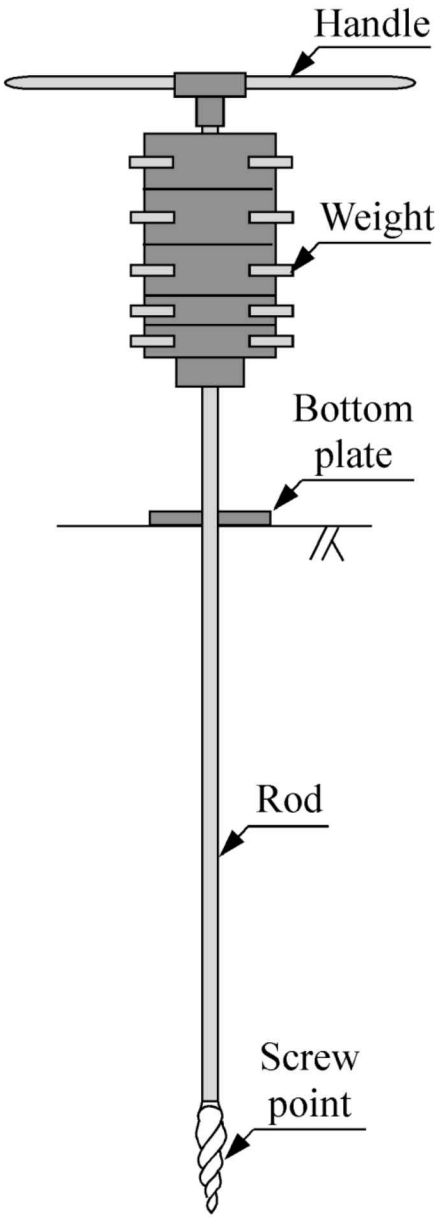
Jukkengawa River

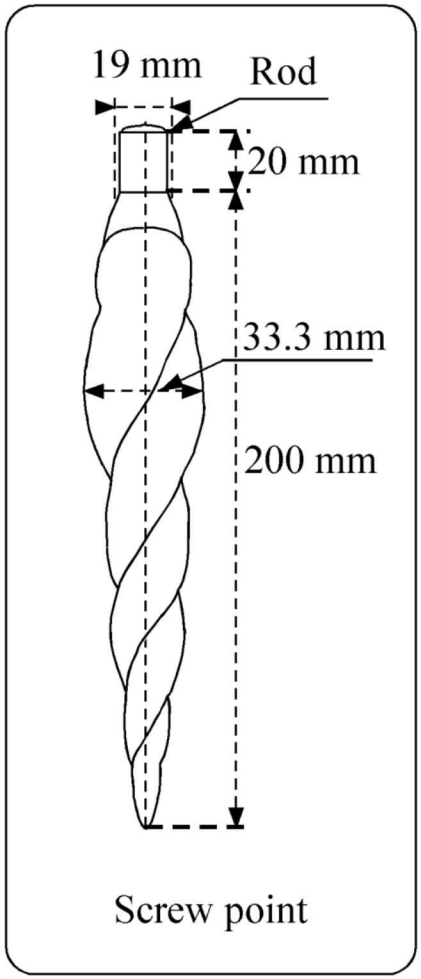
Lots of sand boils

Tonegawa River

Lots of sand boils
on dry river bed

Swedish weight sounding tests





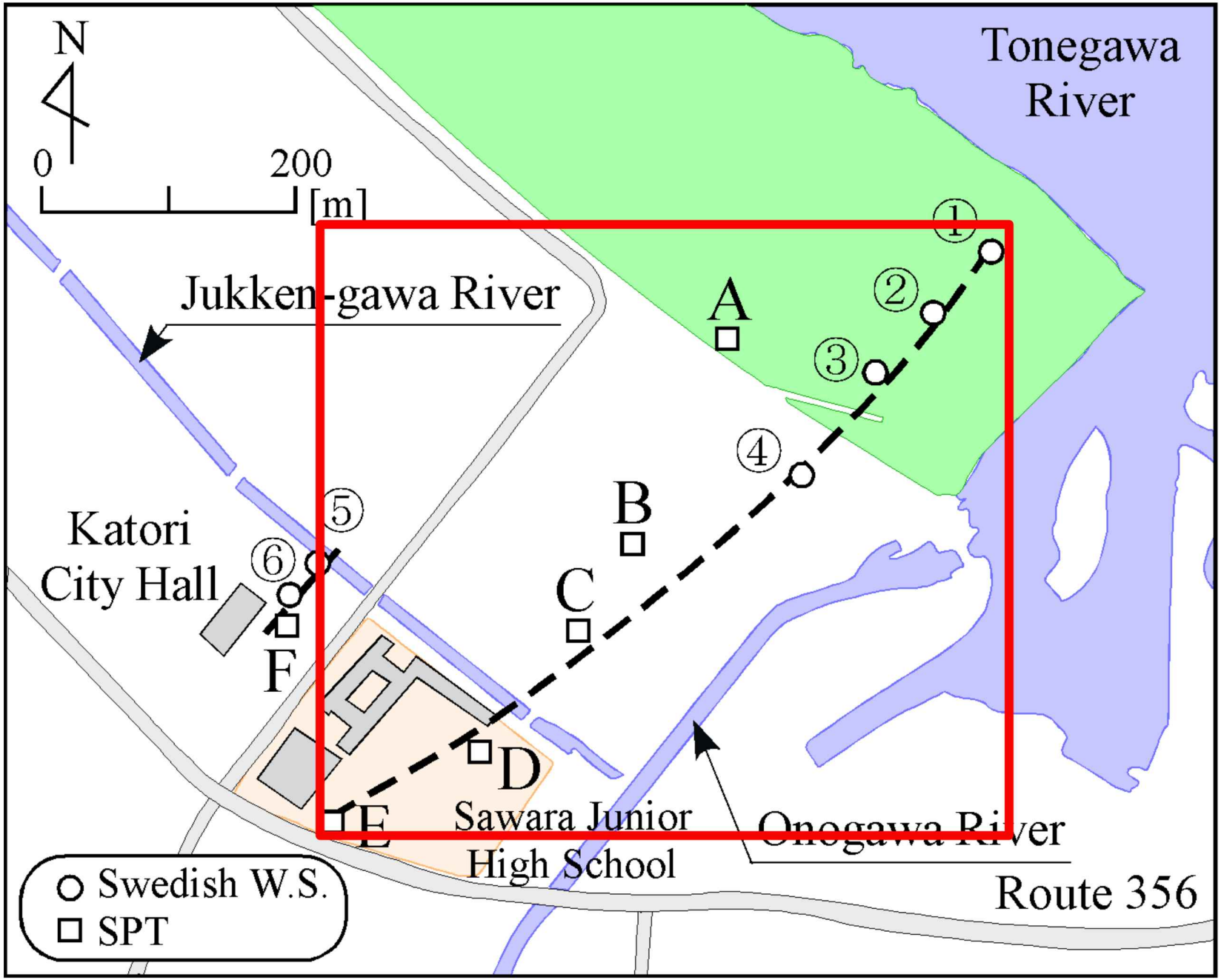
Static penetration :

Screw-shaped point (5 kg) is statically penetrated by putting several weights (10, 10, 25, 25, 25 kg) stepwise to reach total load of 100 kg.

At each load increment, the depth of static penetration is measured and the total weight is denoted as W_{sw} (kN).

Rotational penetration :

Horizontal handle is rotated. Number of half a turn necessary to penetrate the rod through 25 cm is counted as Na (ht/25cm). Then N_{sw} (ht/m) is determined.


N
0
200
[m]
Tonegawa
River
Jukken-gawa River
①
②
③
④
⑤
⑥
A
B
C
D
E
F
Katori
City Hall
Sawara Junior
High School
Onogawa River
Route 356
Swedish W.S.
SPT

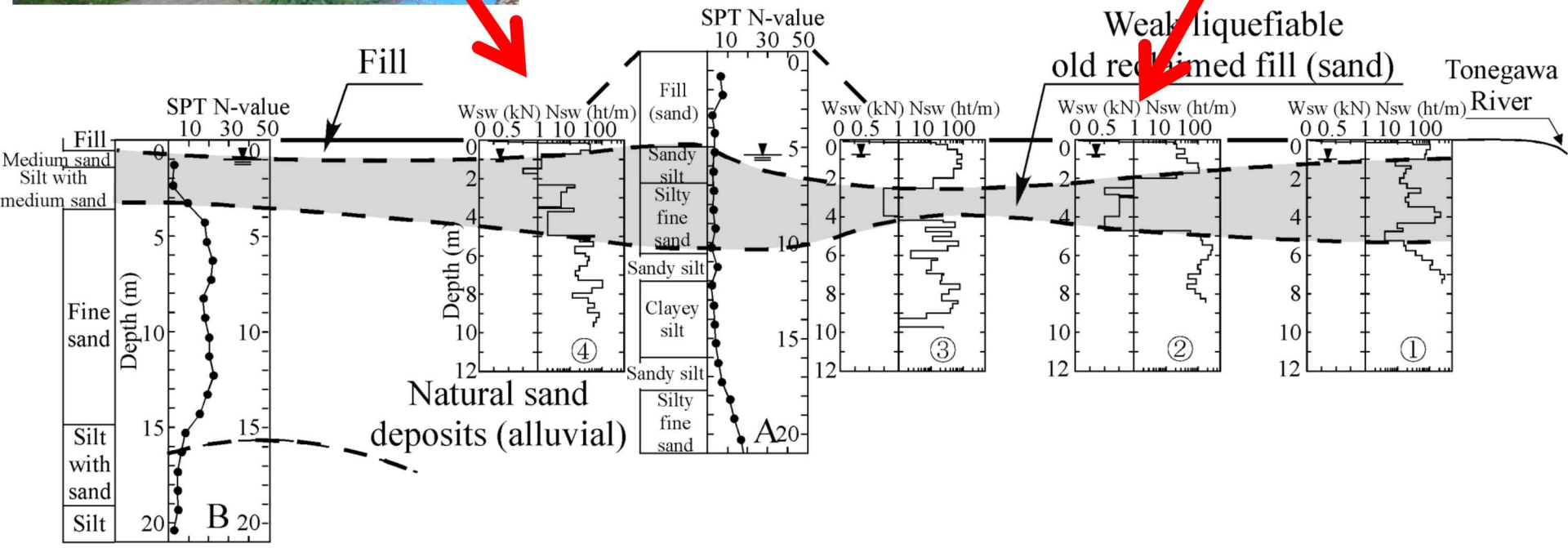
Levee along
Tonegawa River

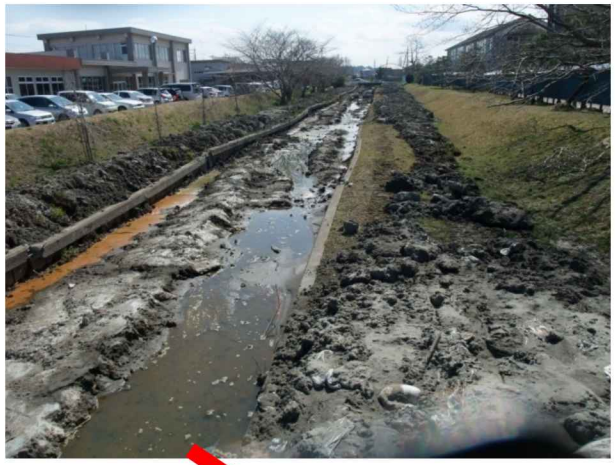
Fill

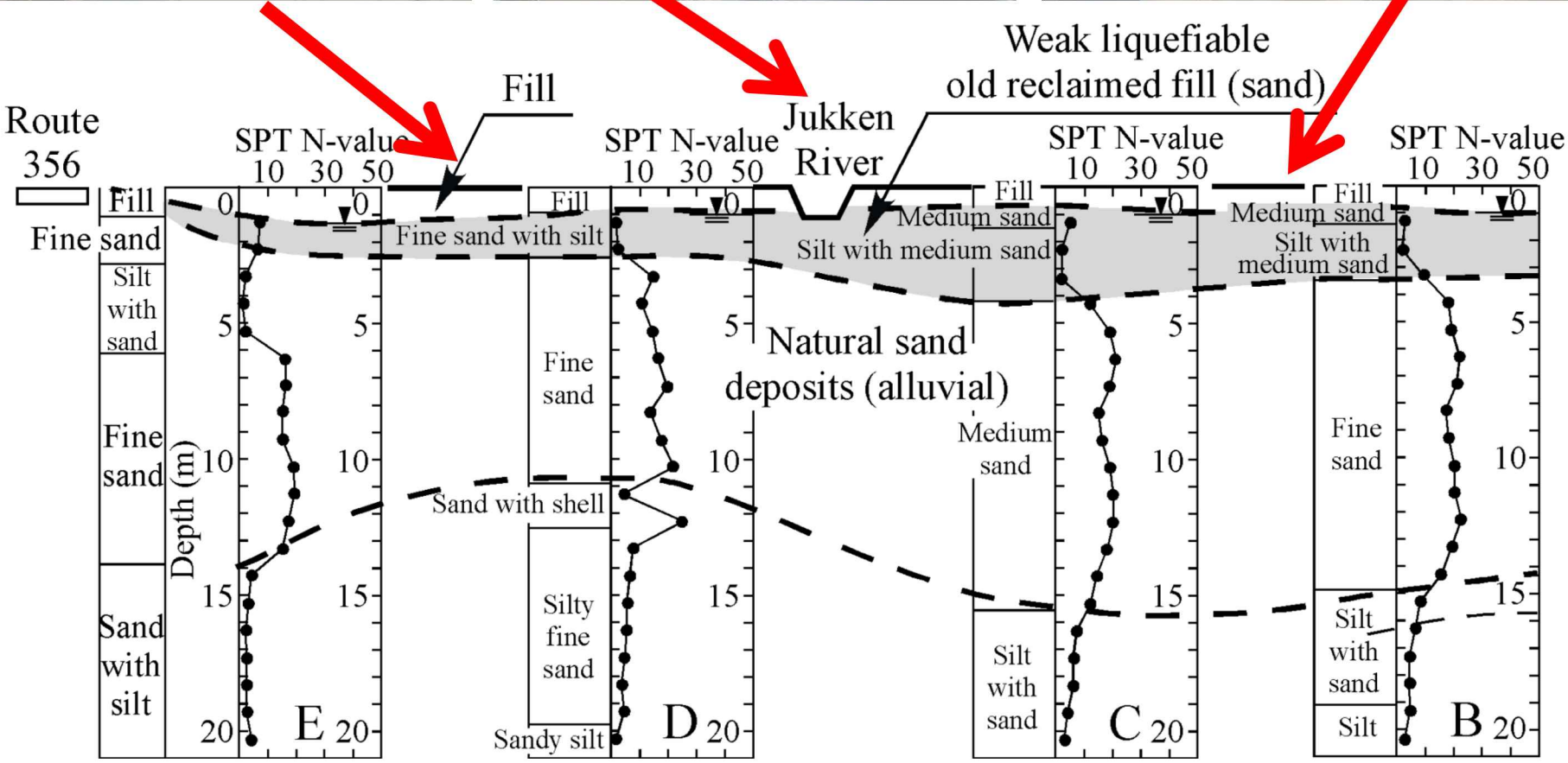
Weak liquefiable
old reclaimed fill (sand)

Tonegawa
River

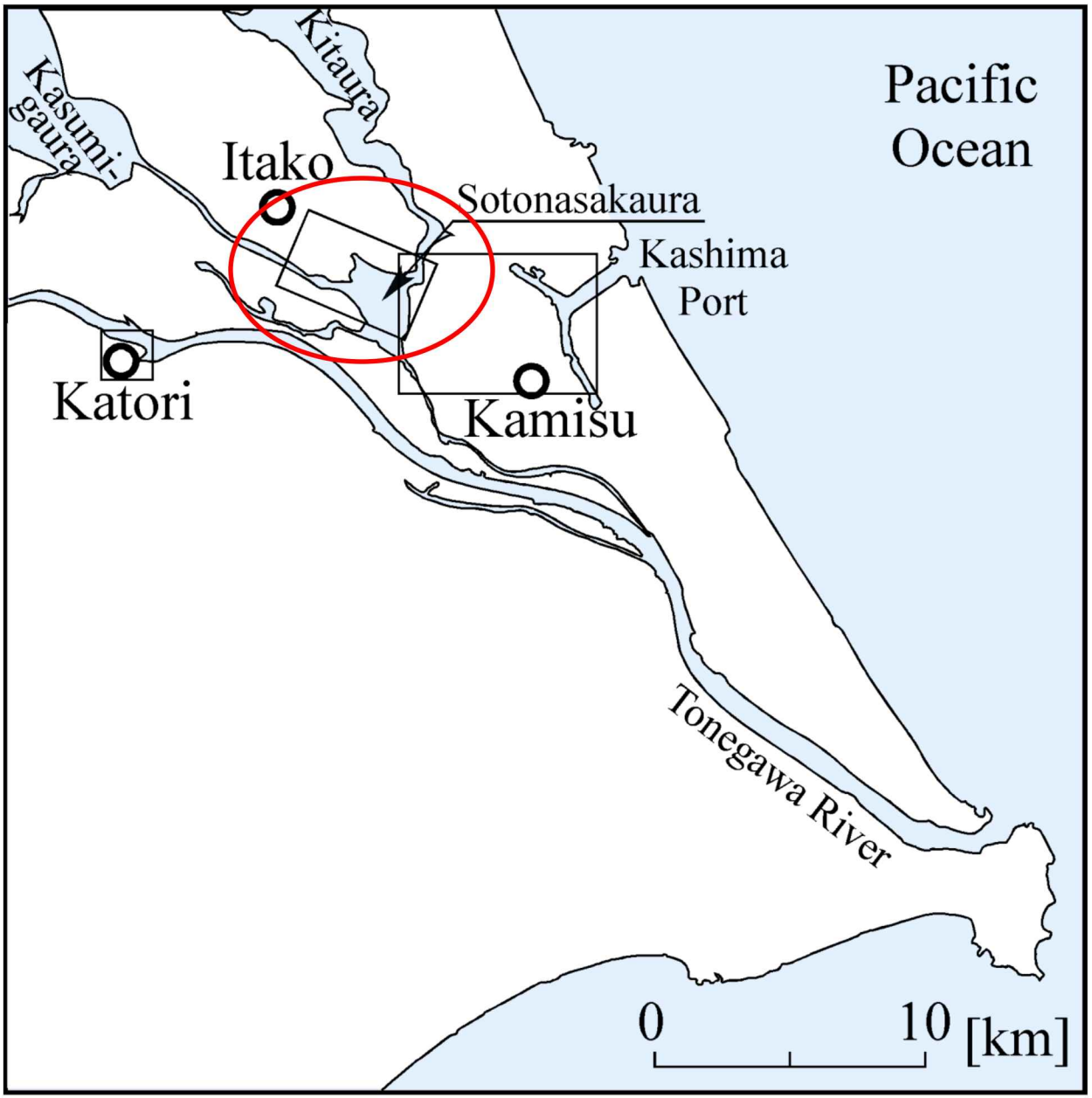
Natural sand
deposits (alluvial)



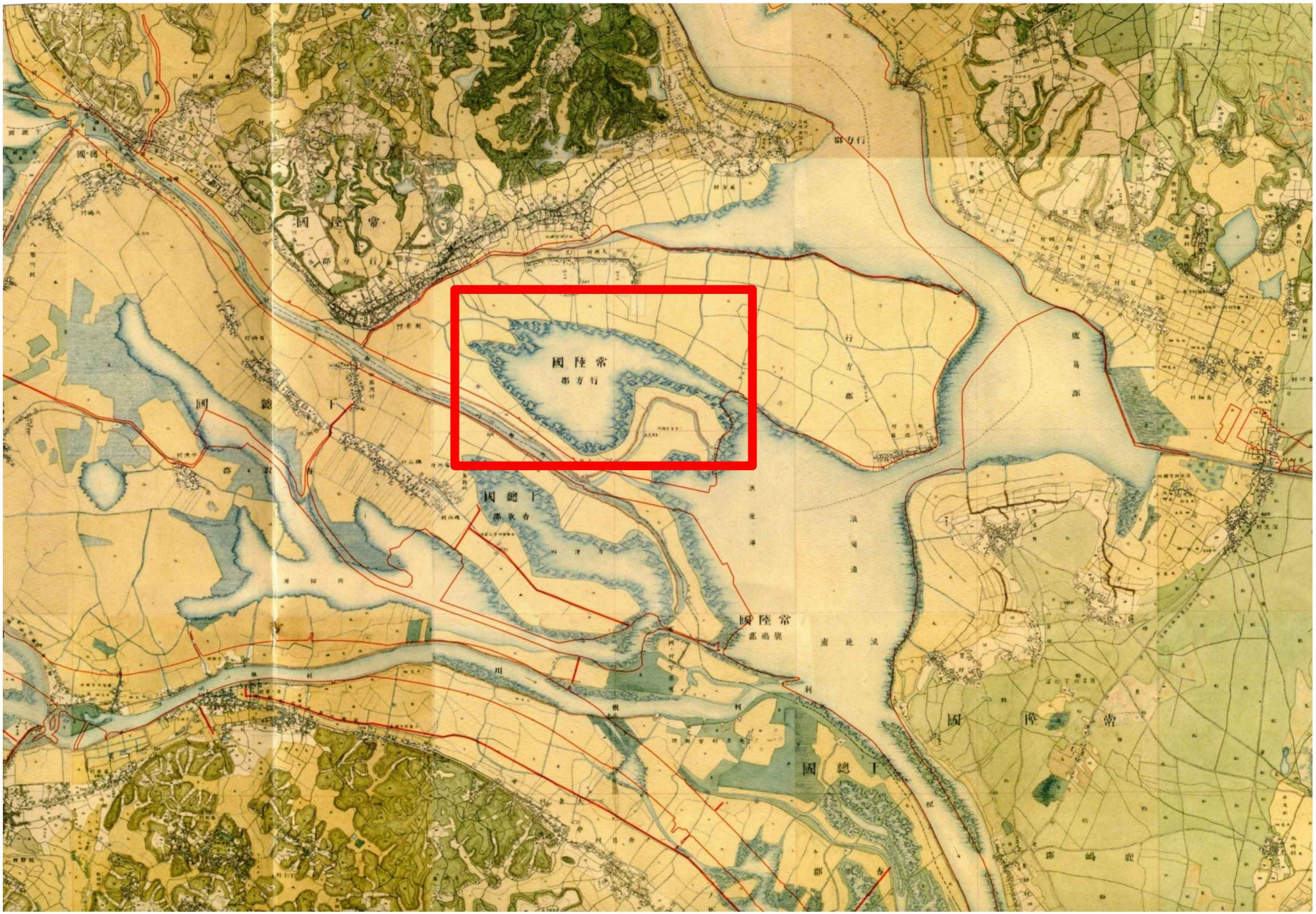



Route 356
Fill
Jukken River
Weak liquefiable old reclaimed fill (sand)
SPT N-value
10 30 50
Depth (m)
Fill
Fine sand
Silt with sand
Fine sand
Sand with silt
Fine sand with silt
Sand with shell
Silty fine sand
Sandy silt
Natural sand deposits (alluvial)
Medium sand
Silt with medium sand
Silt with sand
Silt
E
D
C
B

(2) Hinode, Itako City, Ibaraki



Old map of 1880's (after Tonegawa River Downstream Office 2011)



(after Itako city)

October 26, 1947

1950 Nasaka land reclamation by draining complete

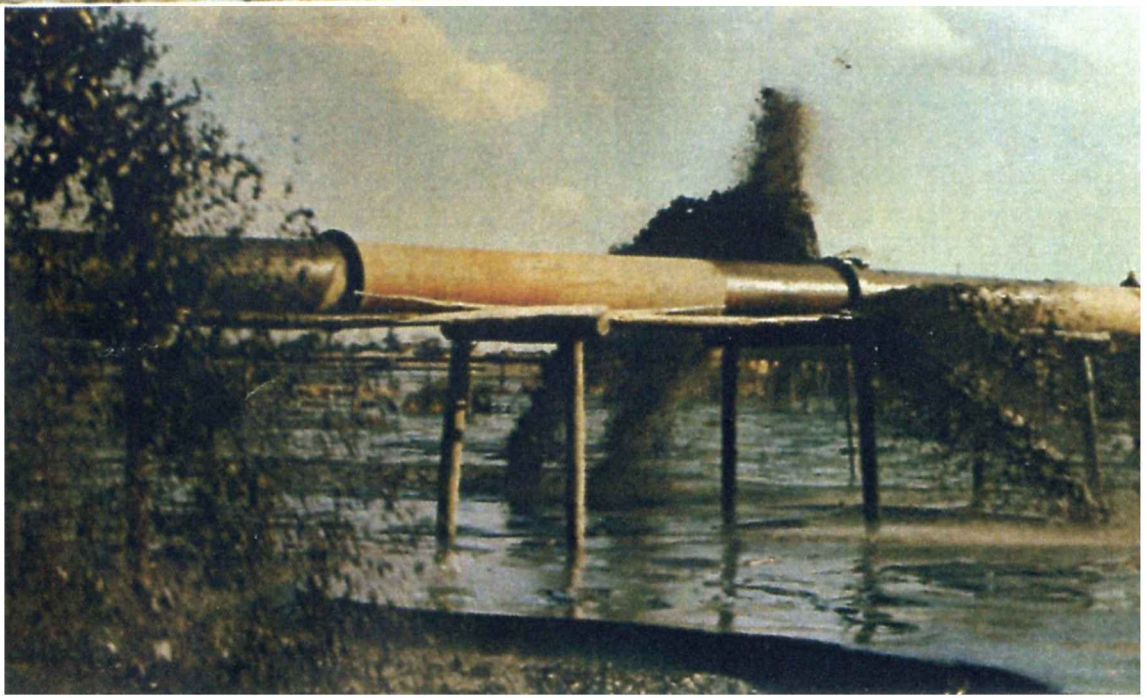
Nasaka land readjustment project (Itako City)

1969 Permission to project

1970 Reclamation by pumping up sea floor sludge started

1971 Reclamation complete

…Then followed the constructions for drainage, road, water supply & sewage, sewage facility, bridge, etc.

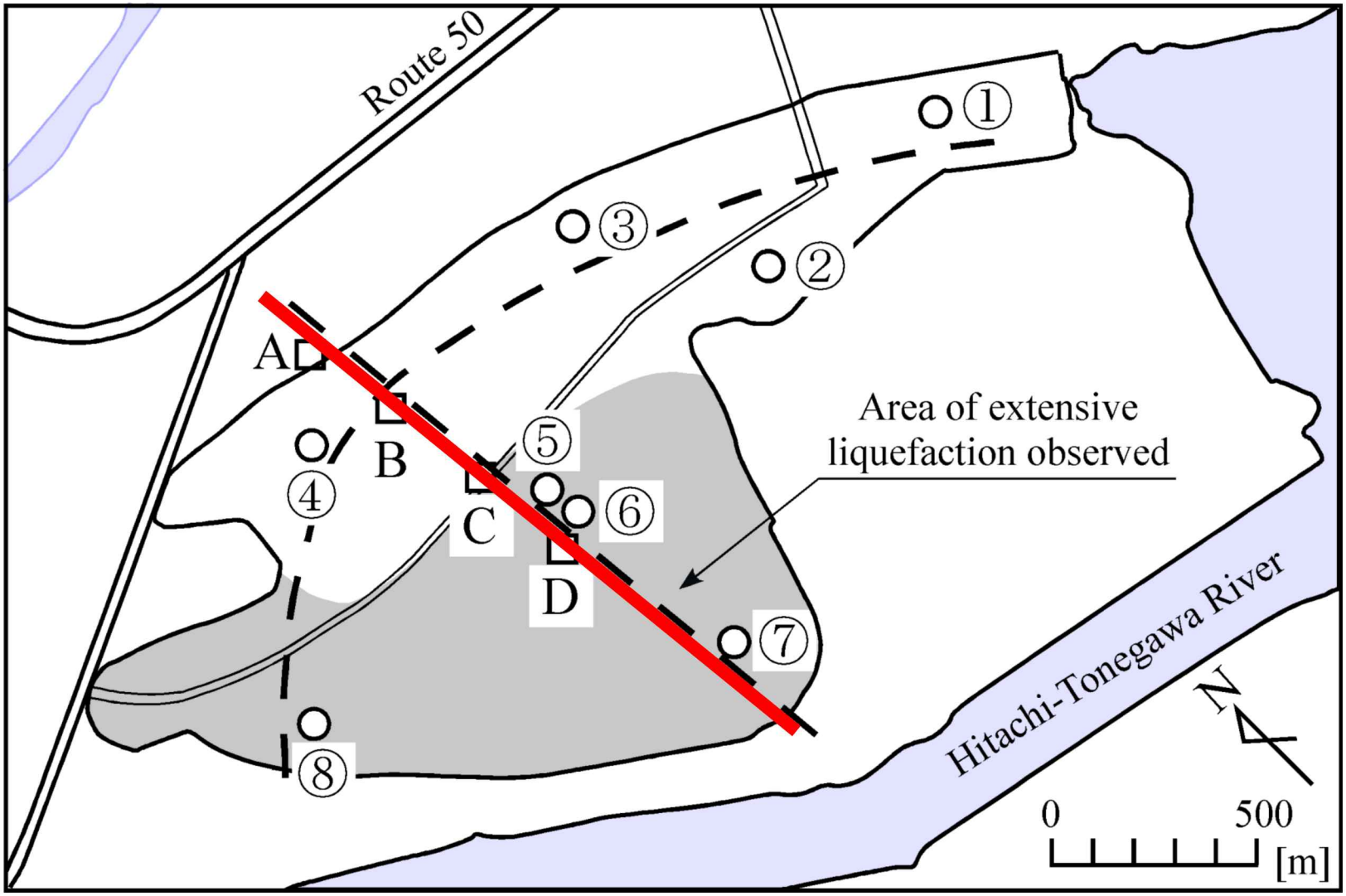


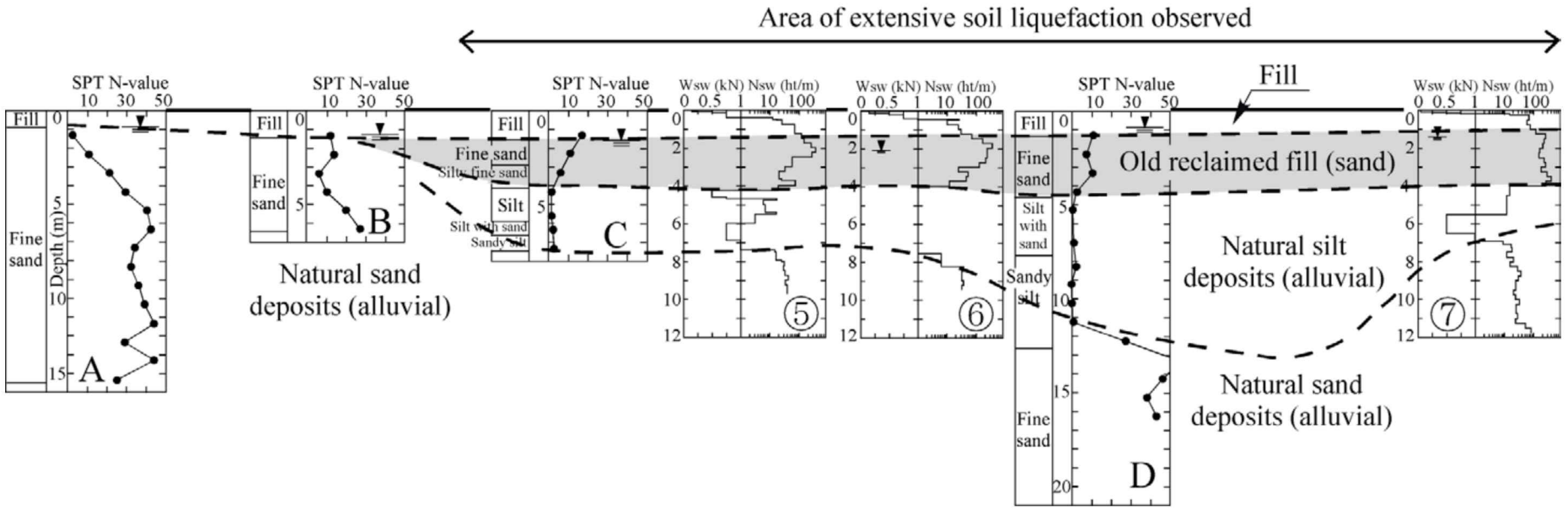
Reclamation by pumping up sea floor sludge

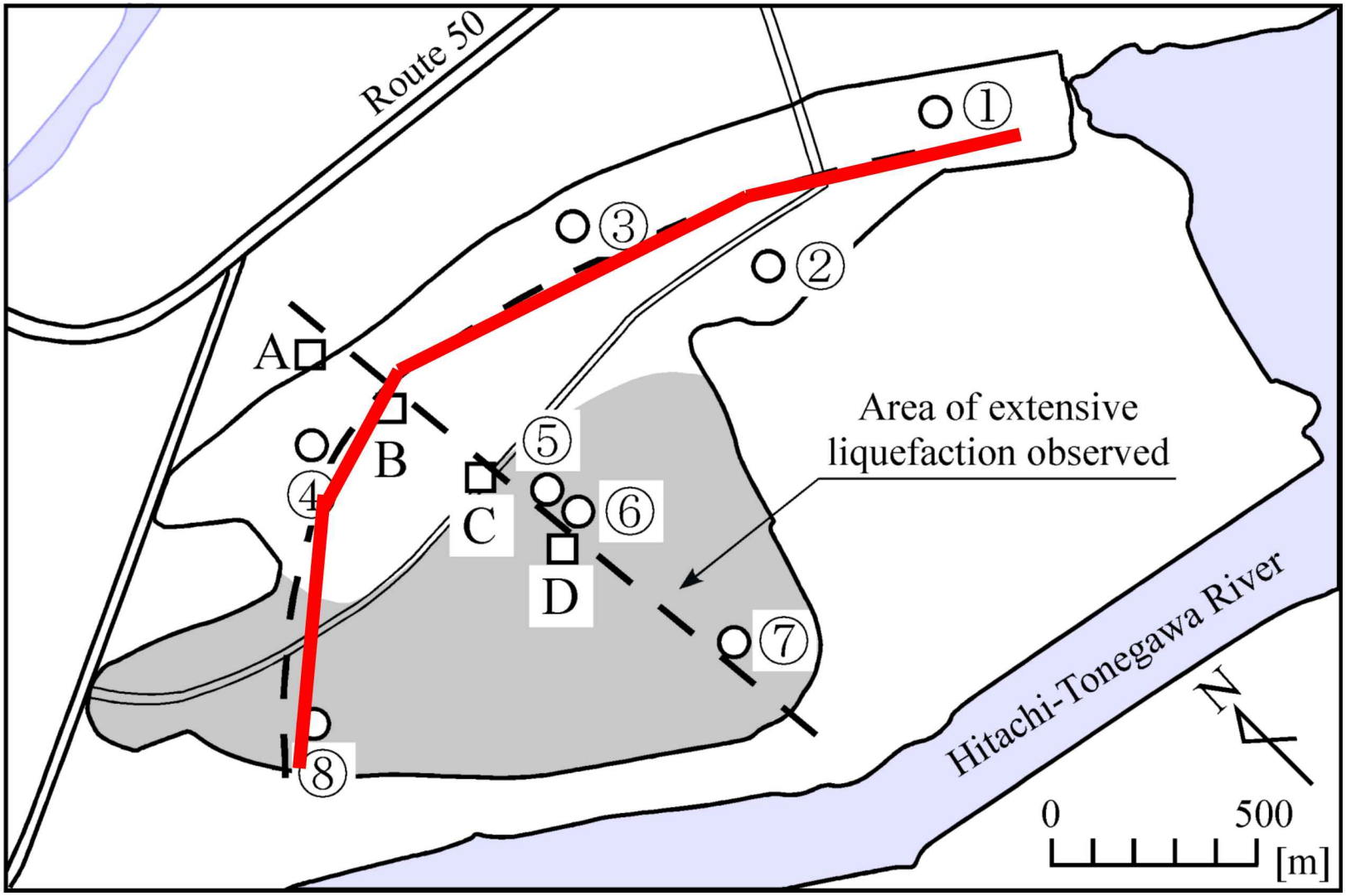
(after Itako city)

(after Itako city)

(after Itako city)

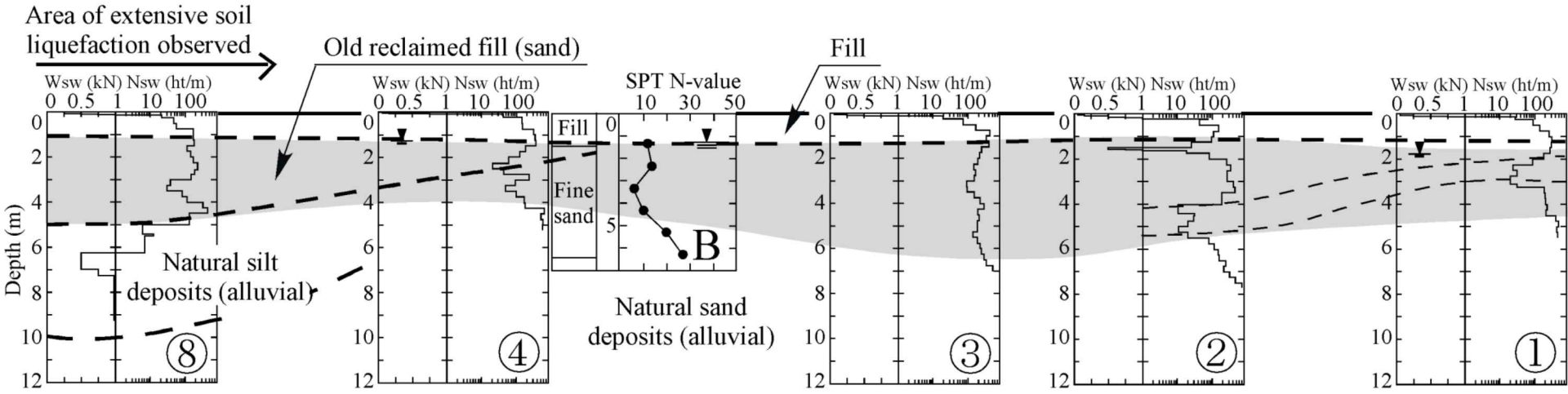

Route 50
①
②
③
A
B
C
D
④
⑤
⑥
⑦
⑧
Area of extensive
liquefaction observed
Hitachi-Tonegawa River
N
0
500
[m]


Area of extensive soil liquefaction observed
SPT N-value
10 30 50
Wsw (kN) Nsw (ht/m)
0 0.5 1 10 100
Depth (m)
Fill
Fine sand
Silty fine sand
Silt
Silt with sand
Sandy silt
Old reclaimed fill (sand)
Natural sand deposits (alluvial)
Natural silt deposits (alluvial)
A
B
C
D
5
6
7

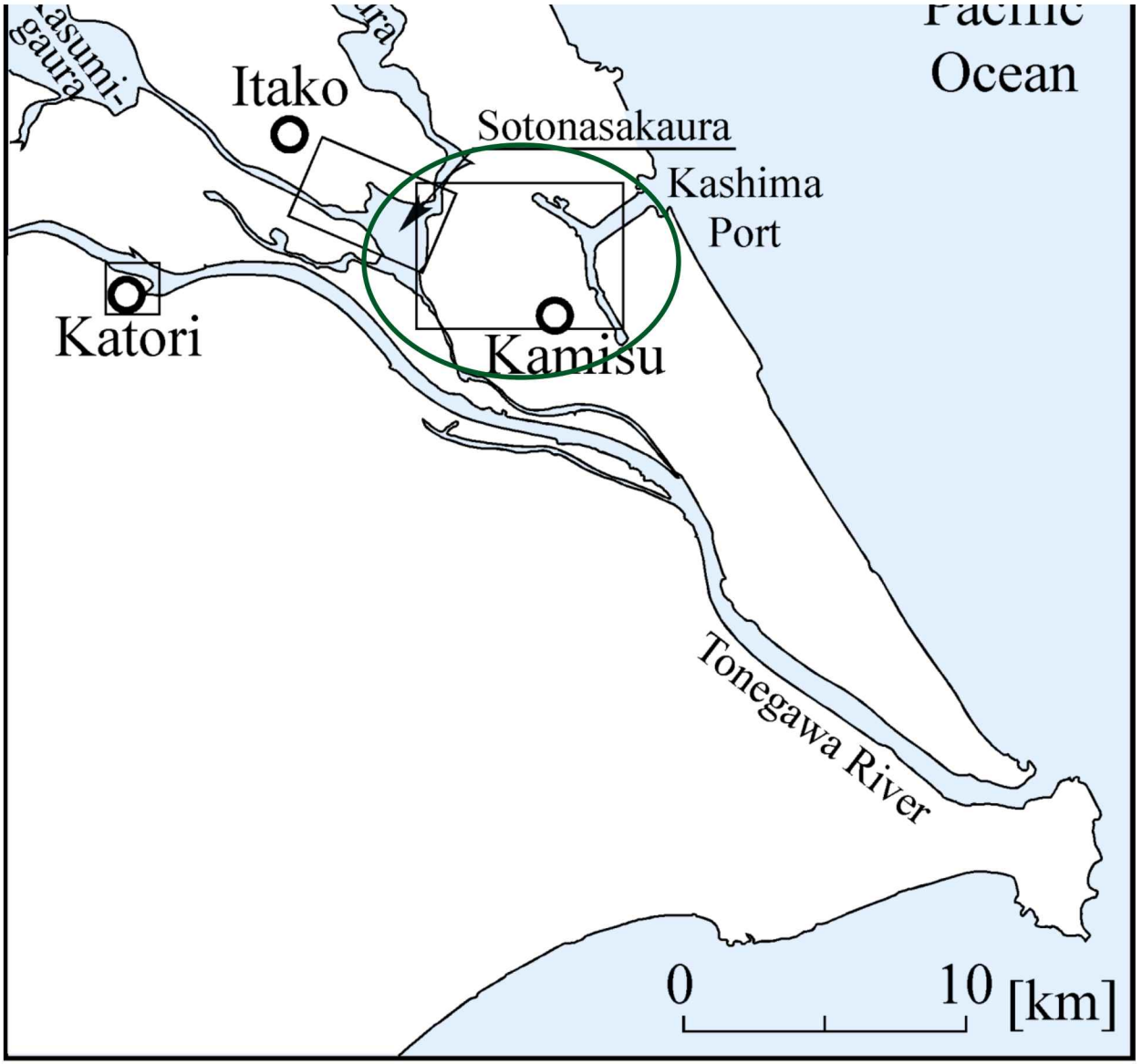

Route 50
①
②
③
A
B
C
D
④
⑤
⑥
⑦
⑧
Area of extensive
liquefaction observed
Hitachi-Tonegawa River
N
0
500
[m]

Extensive soil liquefaction observed over old reclaimed fill

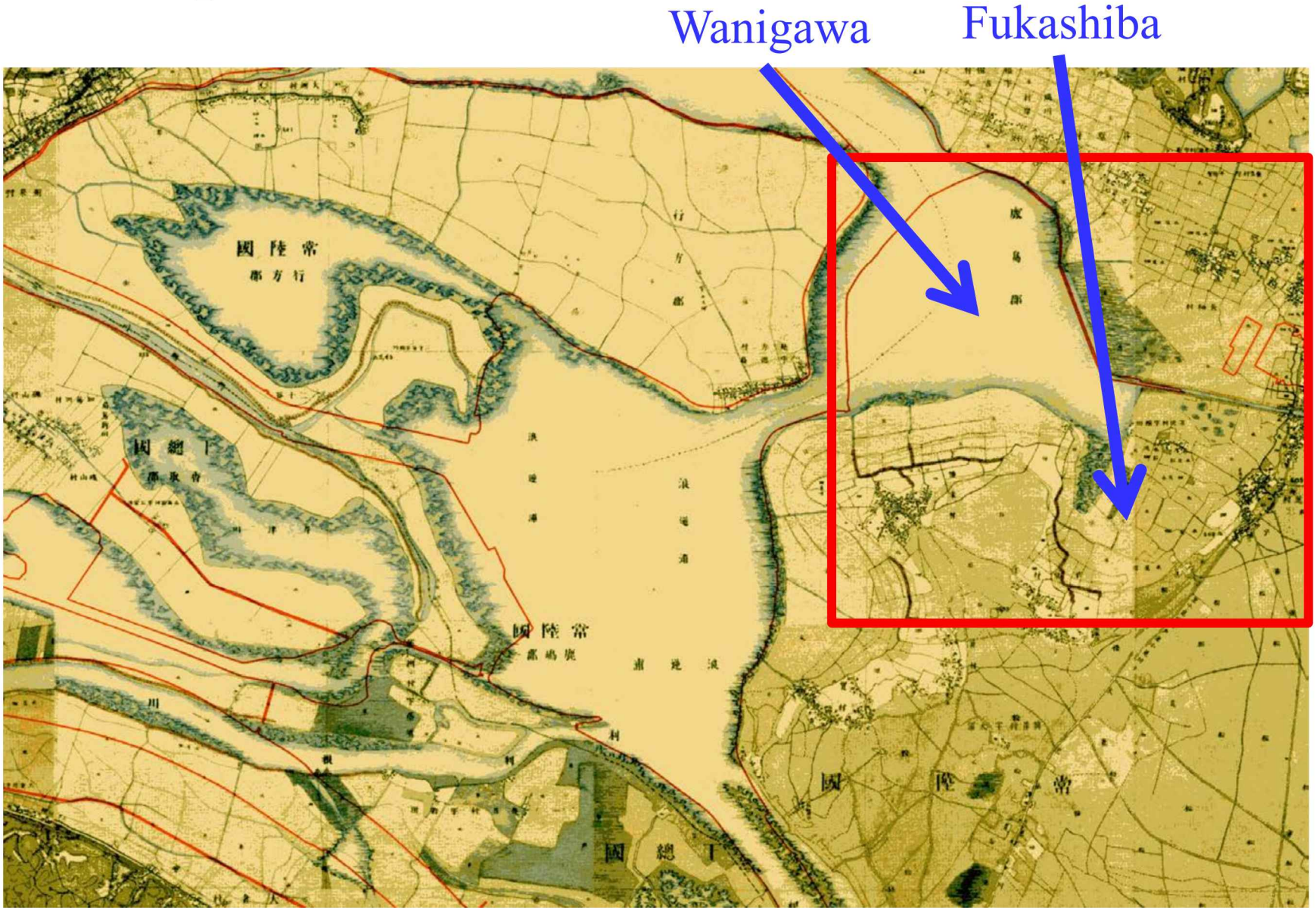
Less extensive soil liquefaction observed over natural deposits



(3) Fukashiba & Gohno-ike Pond, Kamisu City, Ibaraki

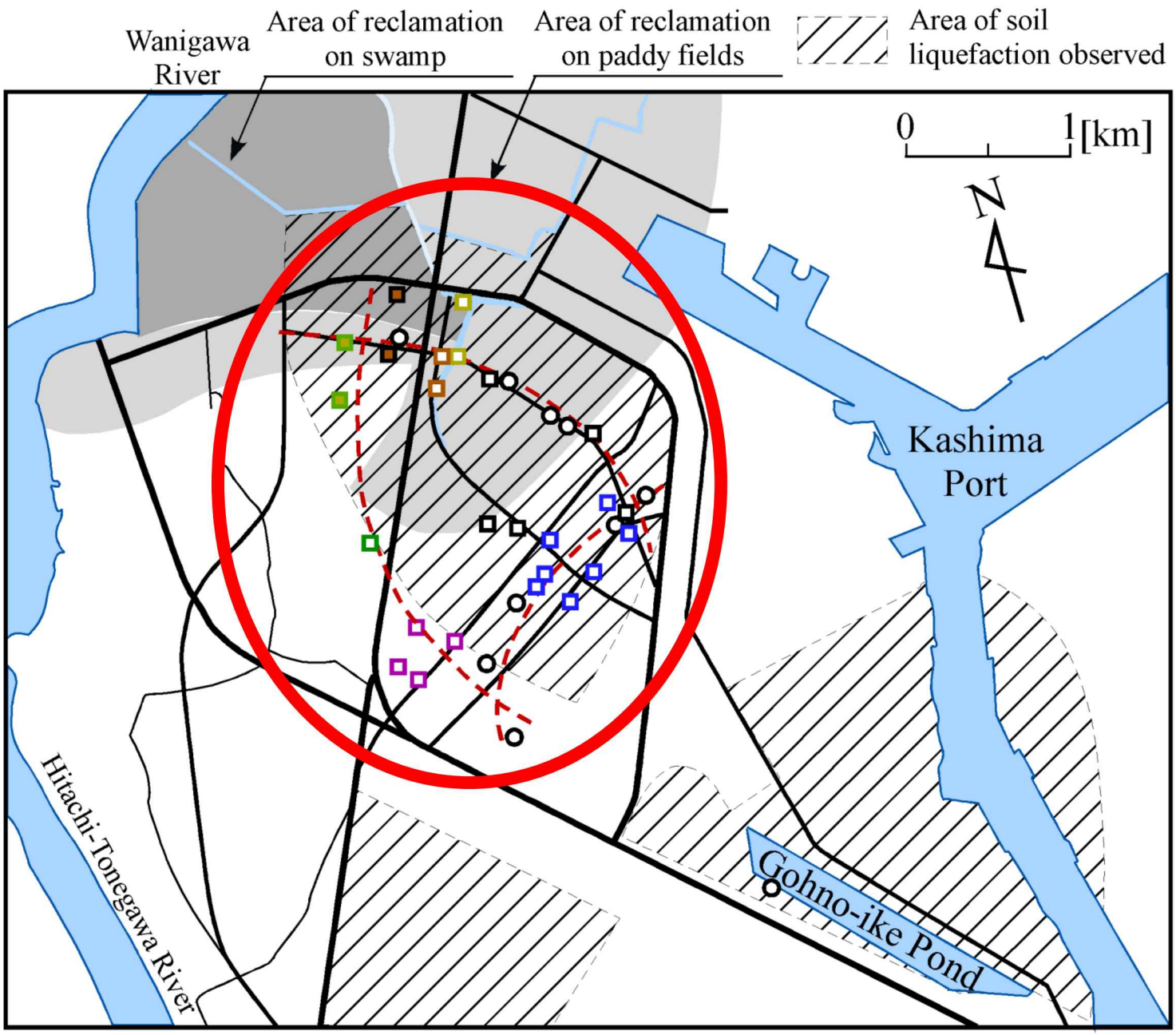


Old map of 1880's (after Tonegawa River Downstream Office 2011)

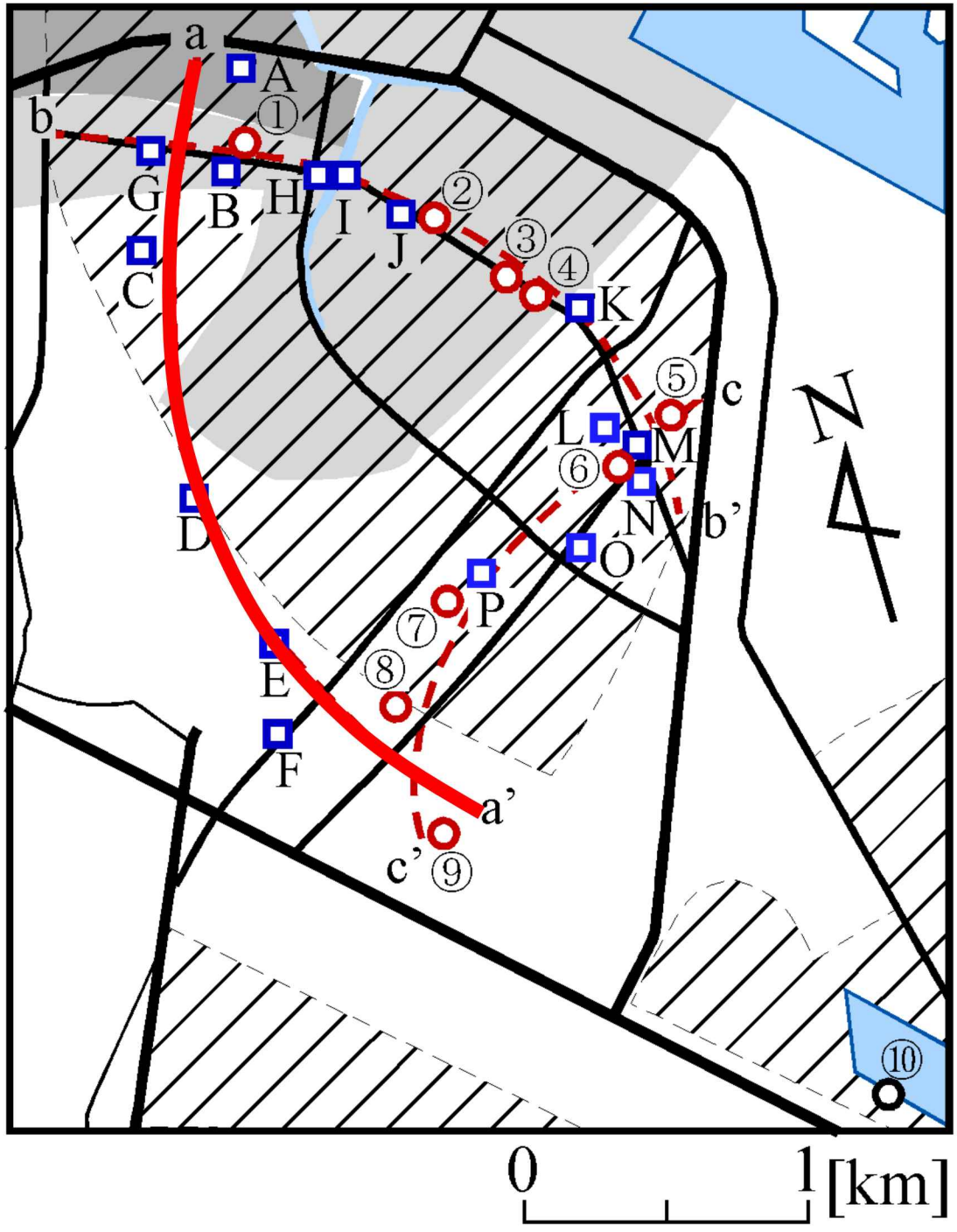


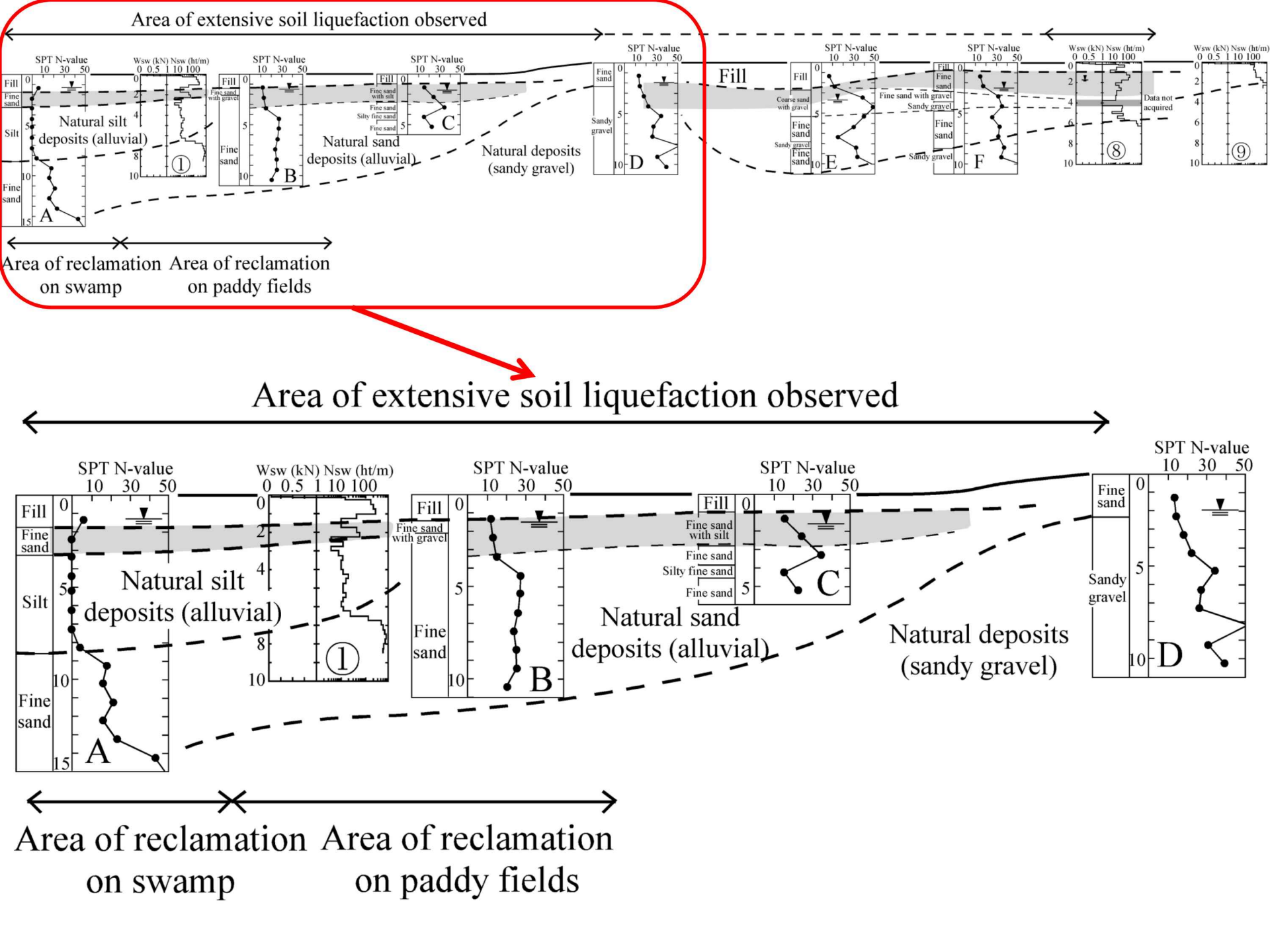
1928 ~ 1933 Wanigawa land reclamation
by draining

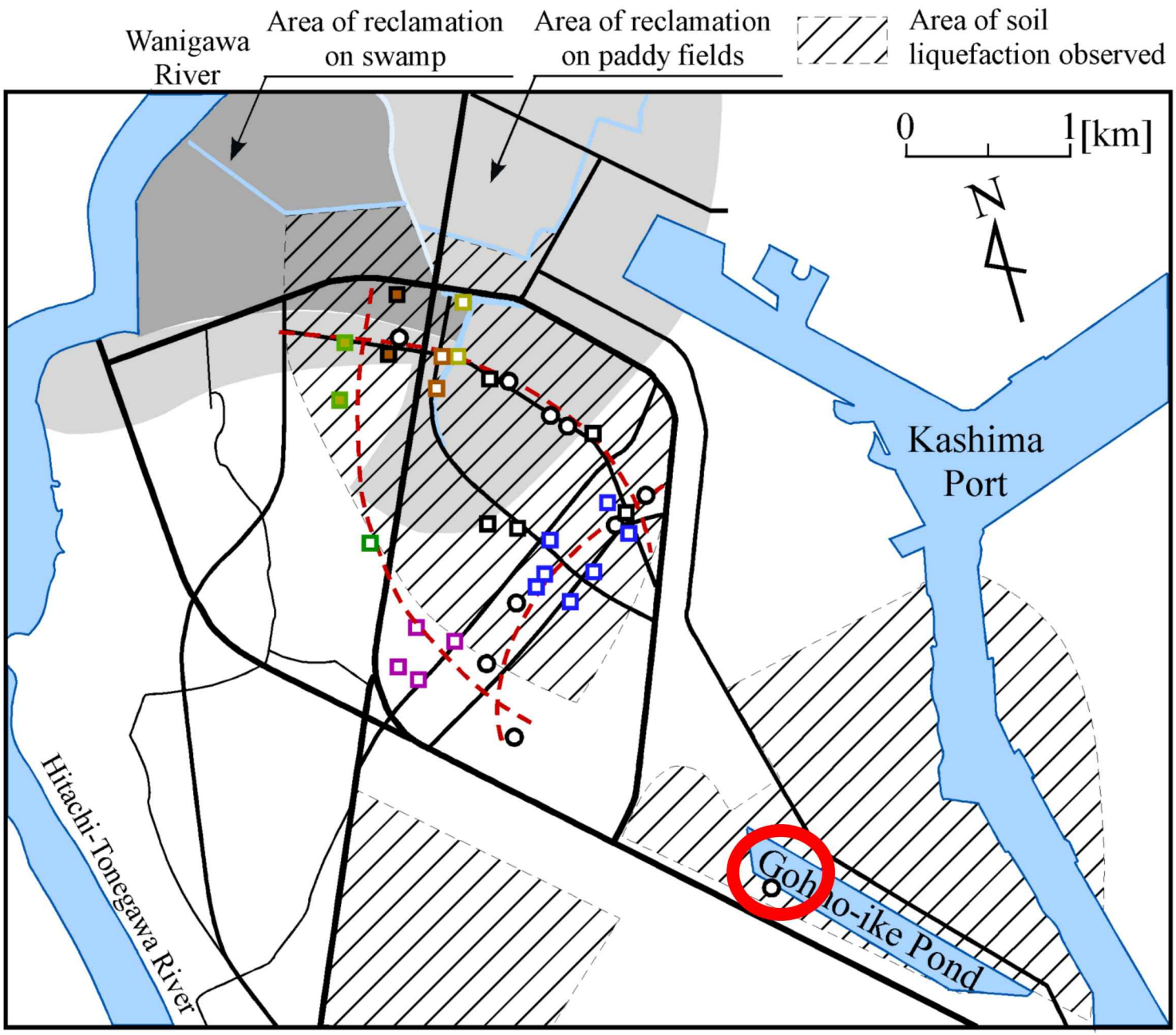
1960's ~ 1980's Gravel digging
& fills reclaimed in gravel pits
at Fukashiba

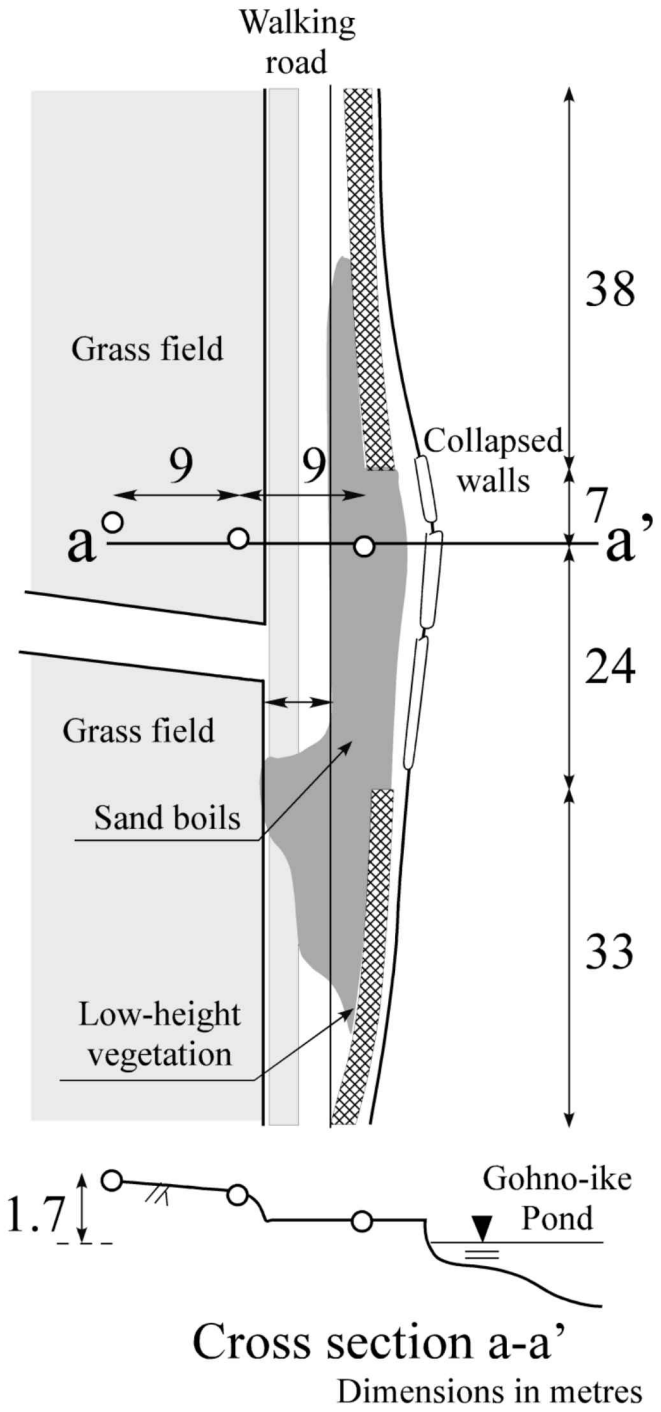

Wanigawa River
Area of reclamation on swamp
Area of reclamation on paddy fields
Area of soil liquefaction observed
0
1 [km]
N
Kashima Port
Hitachi-Tonegawa River
Gohno-ike Pond

Fukashiba, Kamisu


a
A
①
b
G
B
H
I
②
J
③
④
K
C
⑤
c
L
M
⑥
N
b’
D
O
P
⑦
⑧
E
F
a’
c’
⑨
⑩
N
0
1
[km]


Area of extensive soil liquefaction observed
SPT N-value
10 30 50
Wsw (kN) Nsw (ht/m)
0 0.5 1 10 100
Fill
Fine sand
Silt
Natural silt deposits (alluvial)
Fine sand with gravel
Fine sand with silt
Silty fine sand
Natural sand deposits (alluvial)
Natural deposits (sandy gravel)
Coarse sand with gravel
Sands gravel
Sandy gravel
Data not acquired
A
①
B
C
D
E
F
⑧
⑨
Area of reclamation on swamp
Area of reclamation on paddy fields

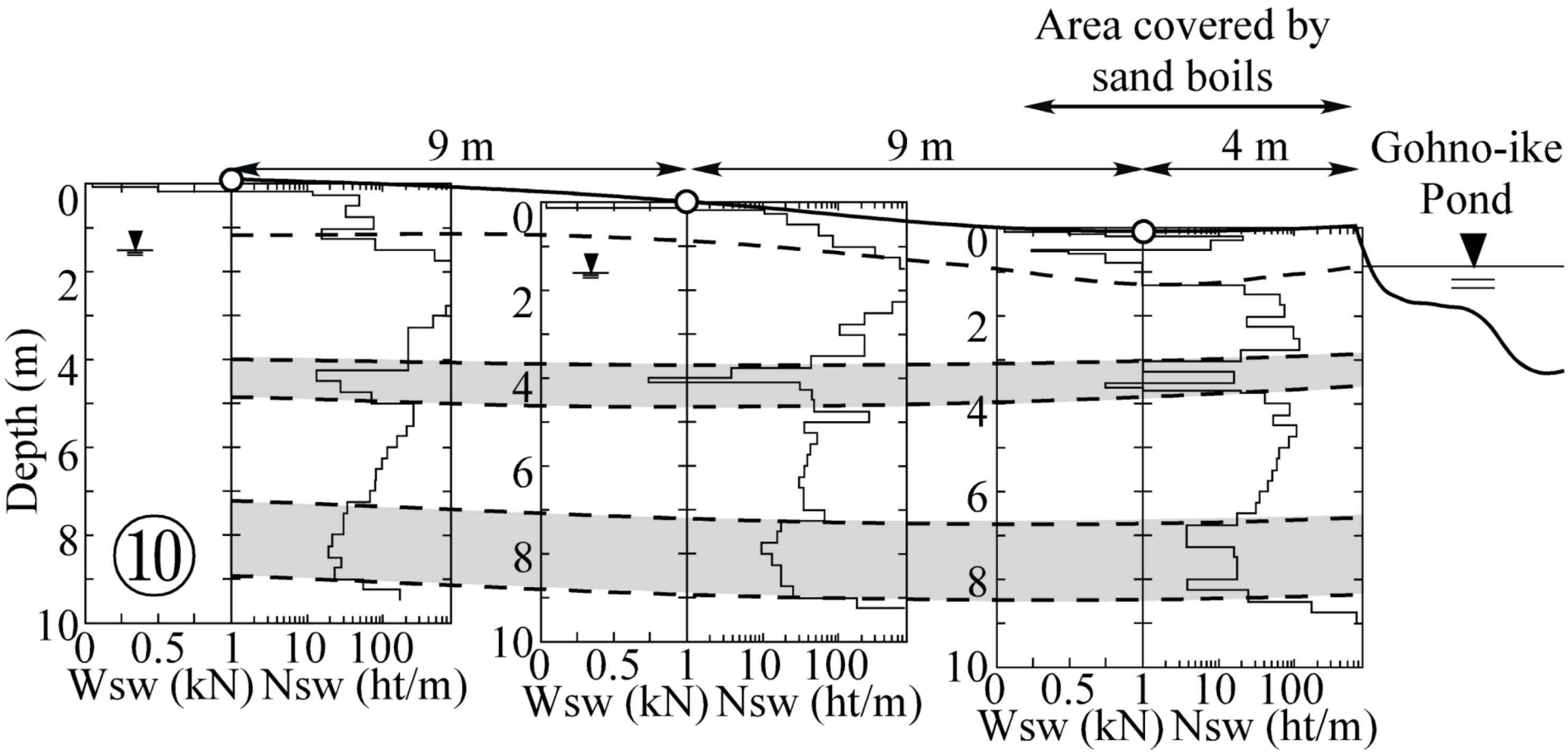

Wanigawa River
Area of reclamation on swamp
Area of reclamation on paddy fields
Area of soil liquefaction observed
0
1 [km]
N
Kashima Port
Hitachi-Tonegawa River
Gohno-ike Pond

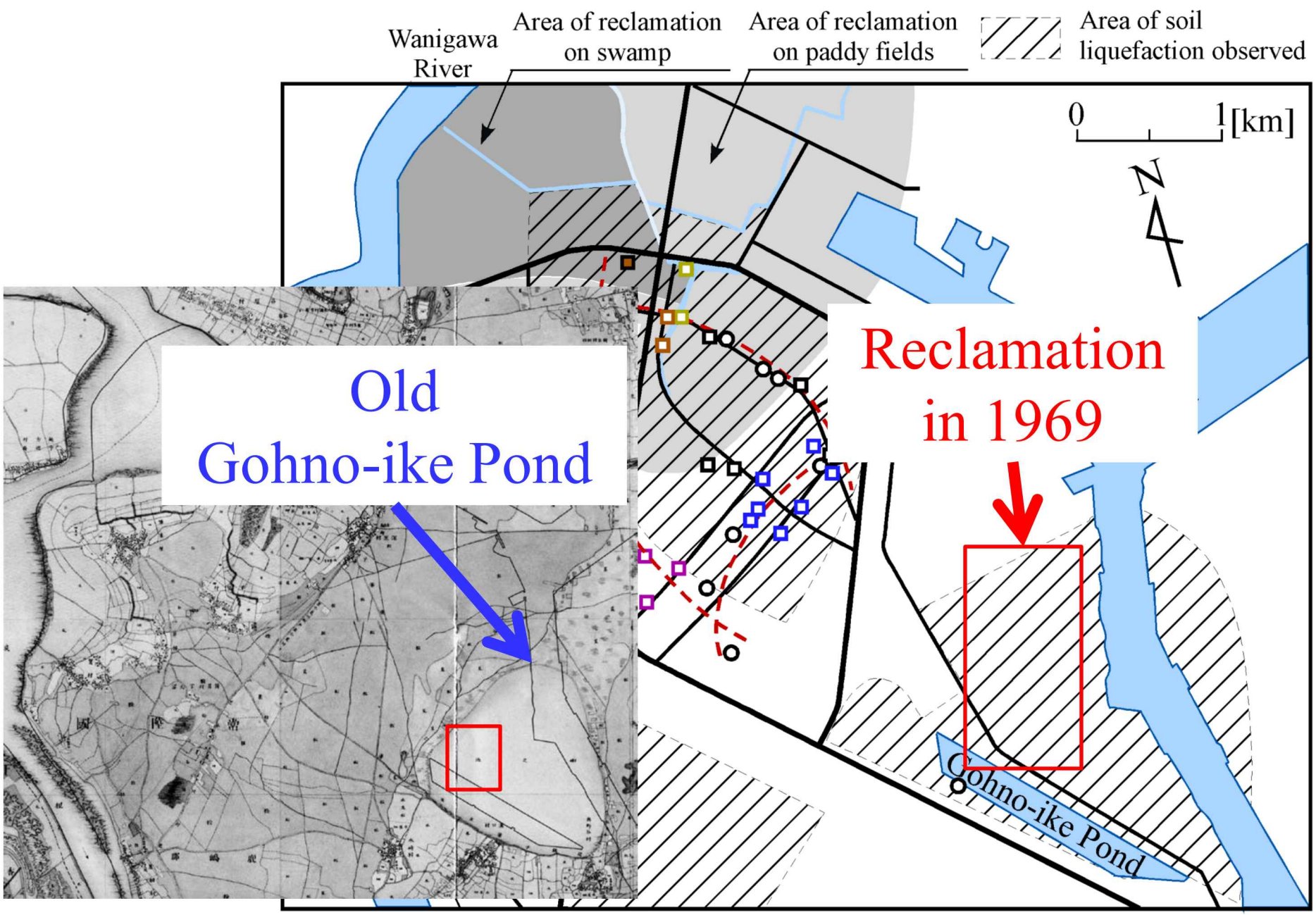


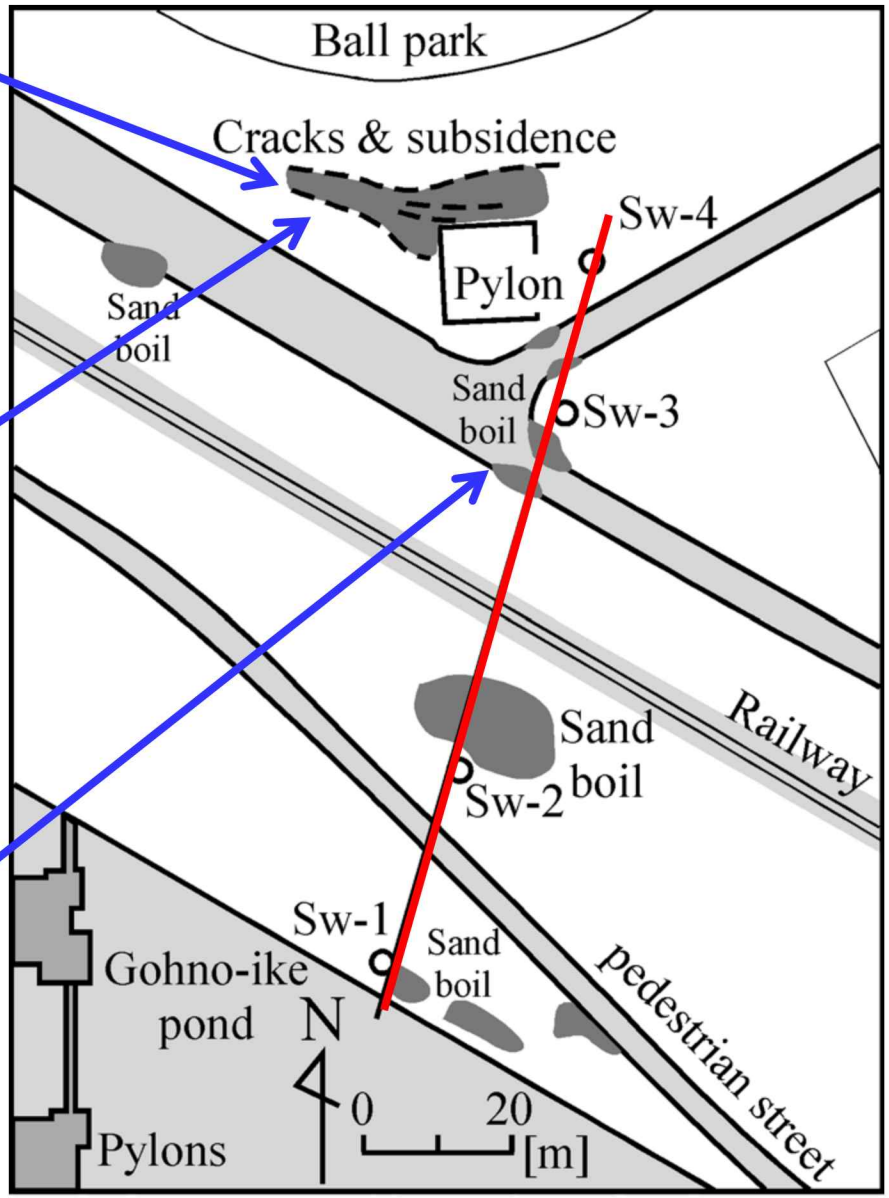
Cross section a-a'

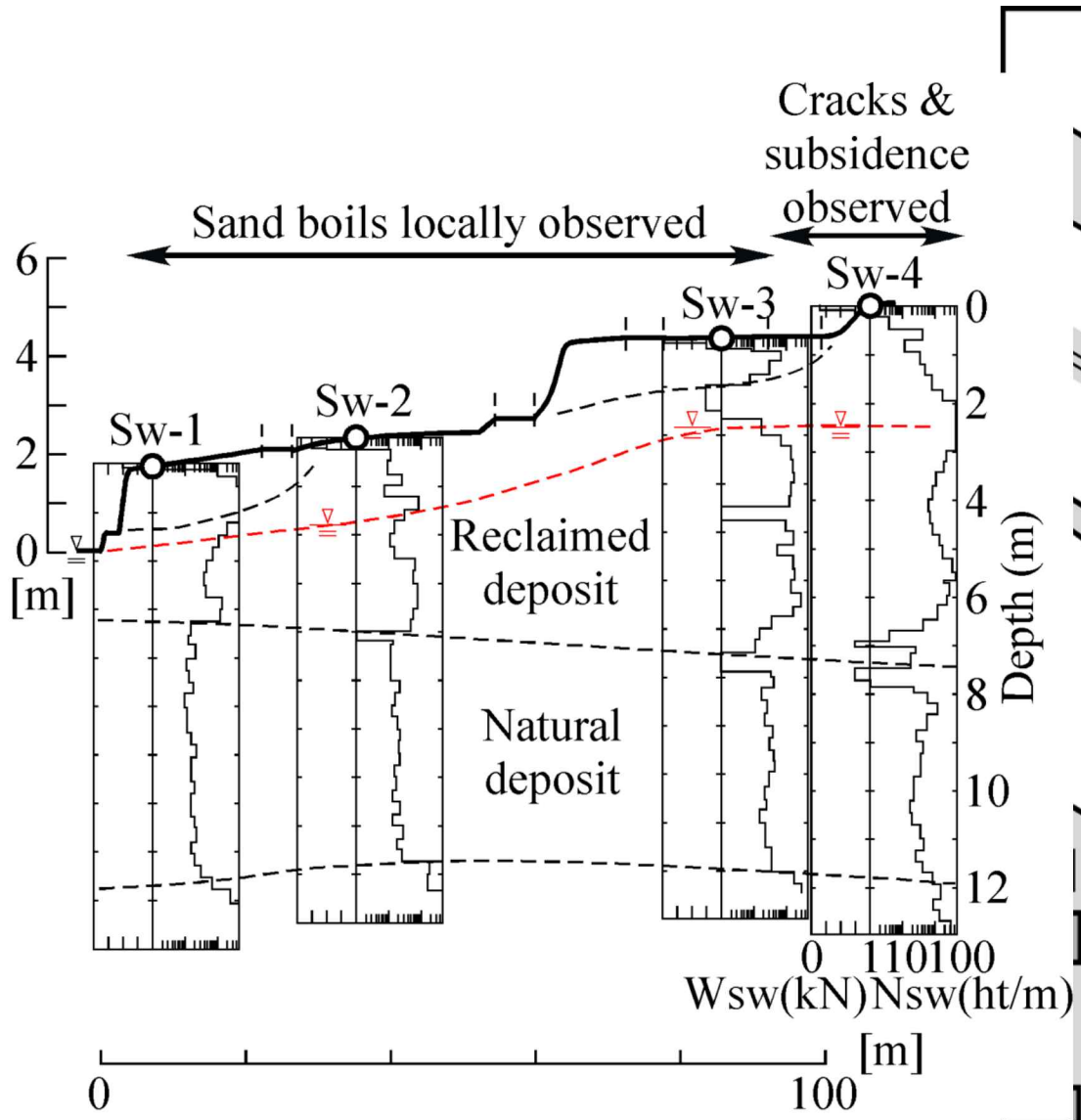
Dimensions in metres

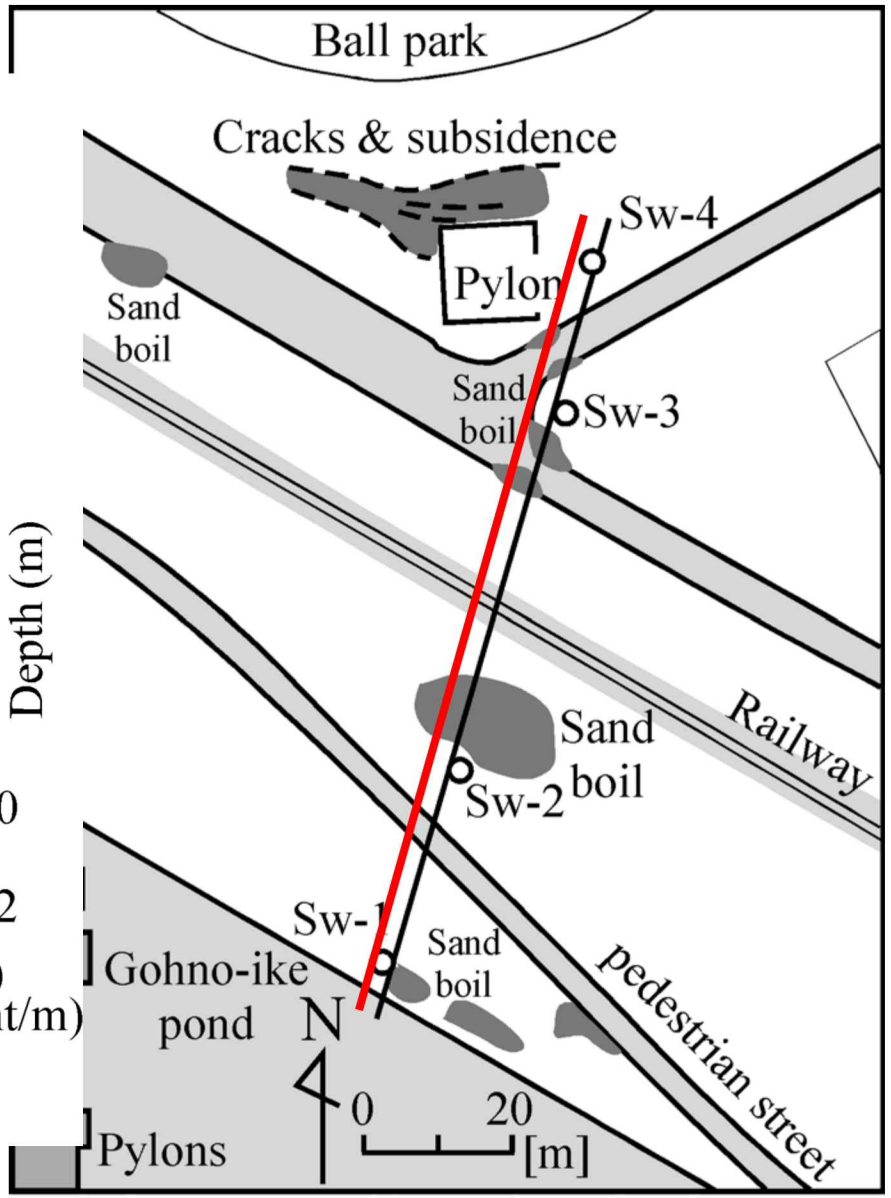
Gohno-ike pond, Kamisu


Area covered by
sand boils
9 m
9 m
4 m
Gohno-ike
Pond
Depth (m)
0
2
4
6
8
10
⑩
0 0.5 1 10 100
Wsw (kN) Nsw (ht/m)
0 0.5 1 10 100
Wsw (kN) Nsw (ht/m)
0 0.5 1 10 100
Wsw (kN) Nsw (ht/m)


Wanigawa River
Area of reclamation on swamp
Area of reclamation on paddy fields
Area of soil liquefaction observed
0
1 [km]
N
Old Gohno-ike Pond
Reclamation in 1969
Gohno-ike Pond

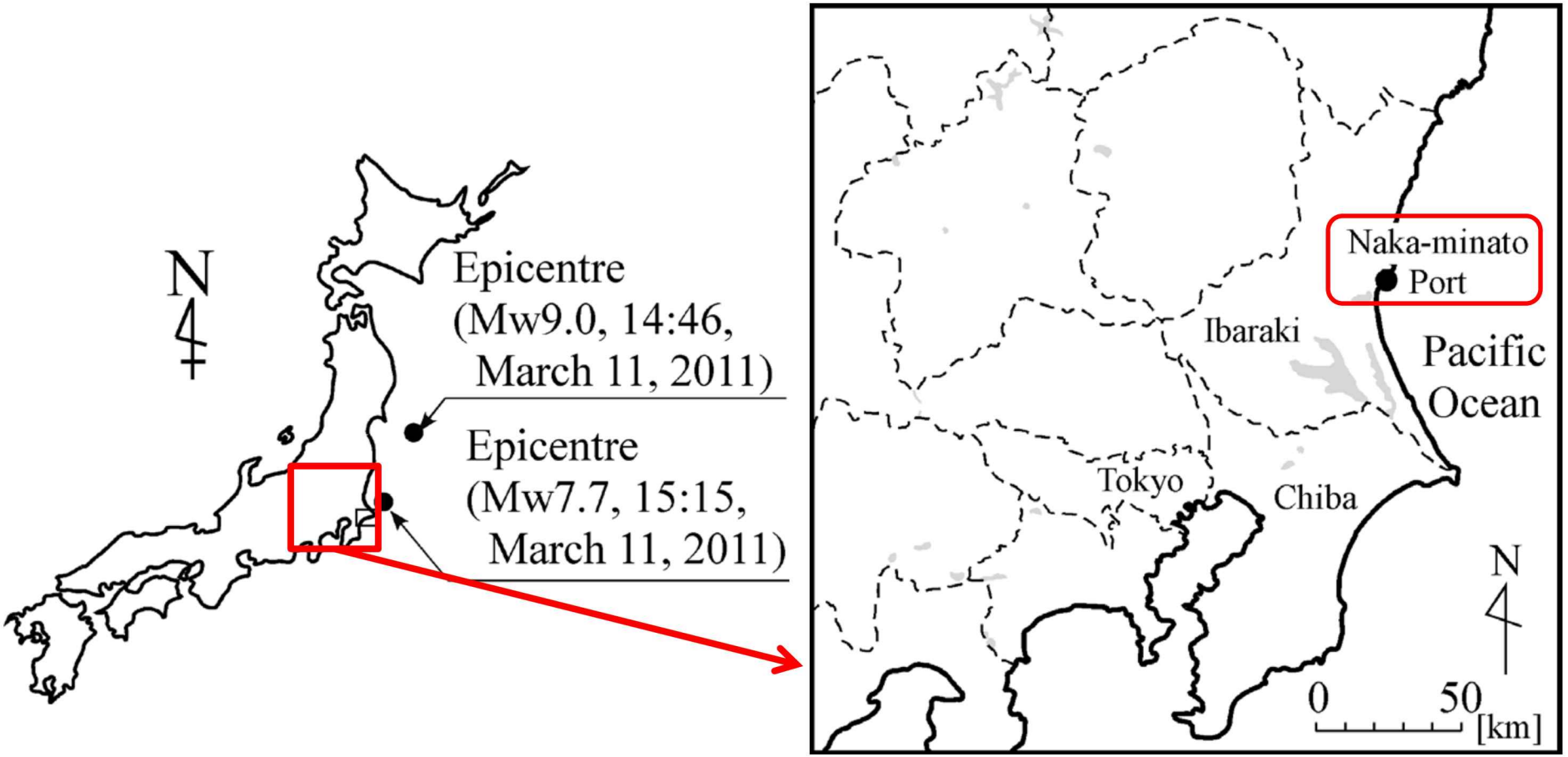

Ball park
Cracks & subsidence
Sw-4
Pylon
Sand boil
Sand boil
Sw-3
Railway
Sand boil
Sw-2
Sw-1
Sand boil
Gohno-ike pond
N
0
20
[m]
Pylons
pedestrian street

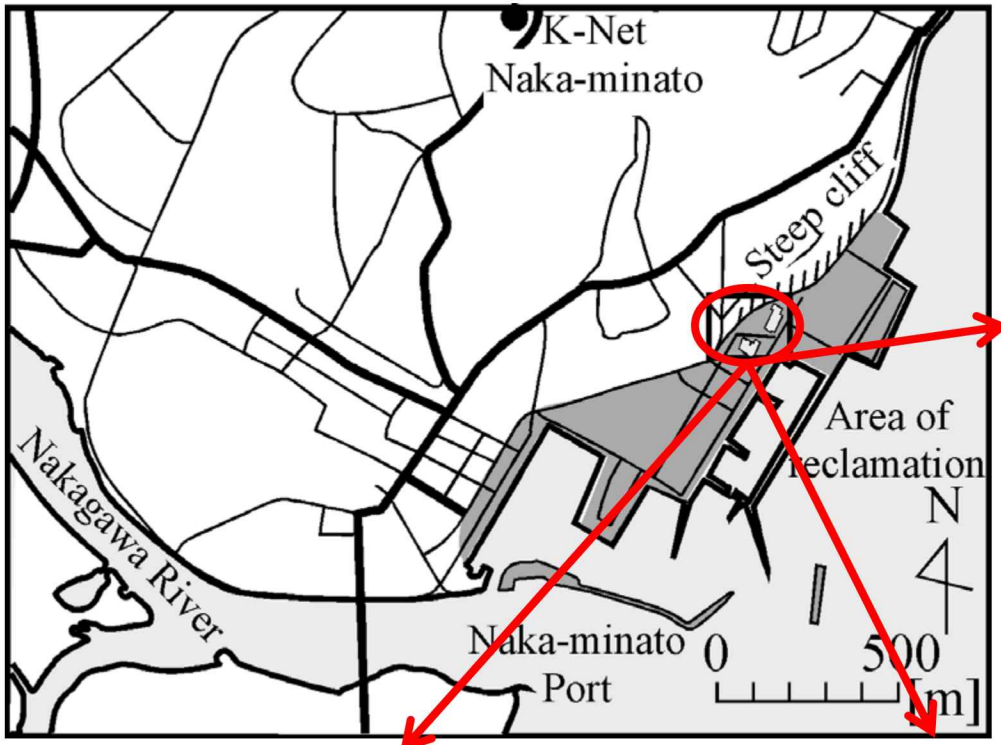

Sand boils locally observed
Cracks & subsidence observed
Sw-1
Sw-2
Sw-3
Sw-4
Reclaimed deposit
Natural deposit
[m]
Depth (m)
Wsw(kN)
Nsw(ht/m)
0
100
[m]


Ball park
Cracks & subsidence
Sw-4
Pylon
Sand boil
Sw-3
Railway
Sw-2
Sw-1
Gohno-ike pond
N
pedestrian street
Pylons
0
20
[m]

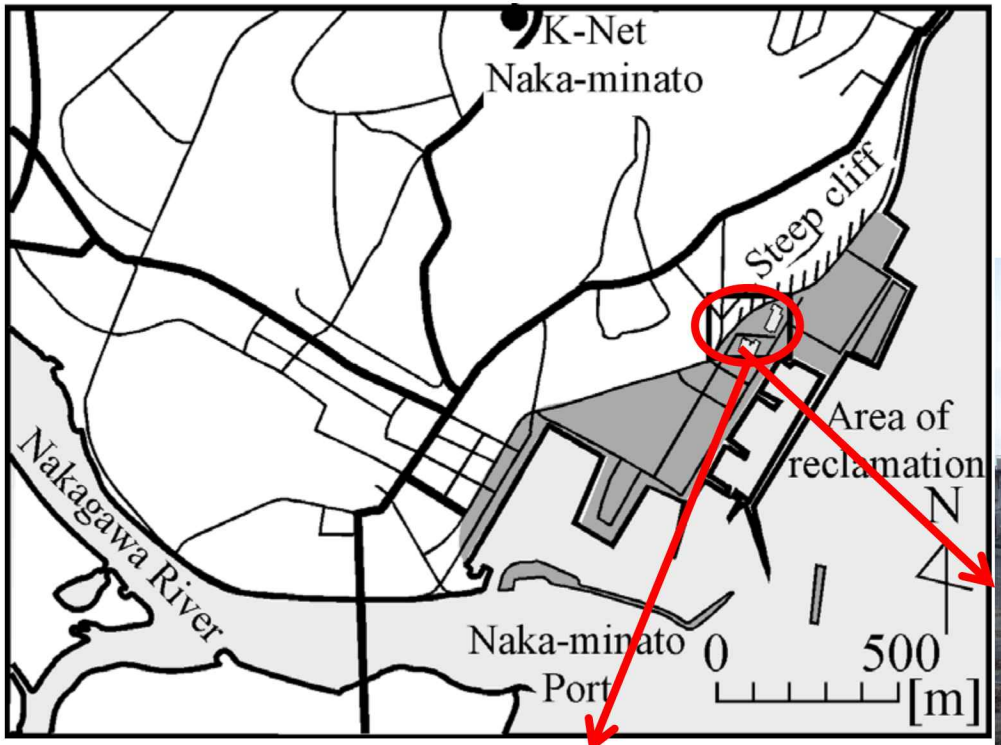
(4) Nakaminato,Hitachinaka City, Ibaraki

Road embankment slip failures
over liquefied reclaimed deposits

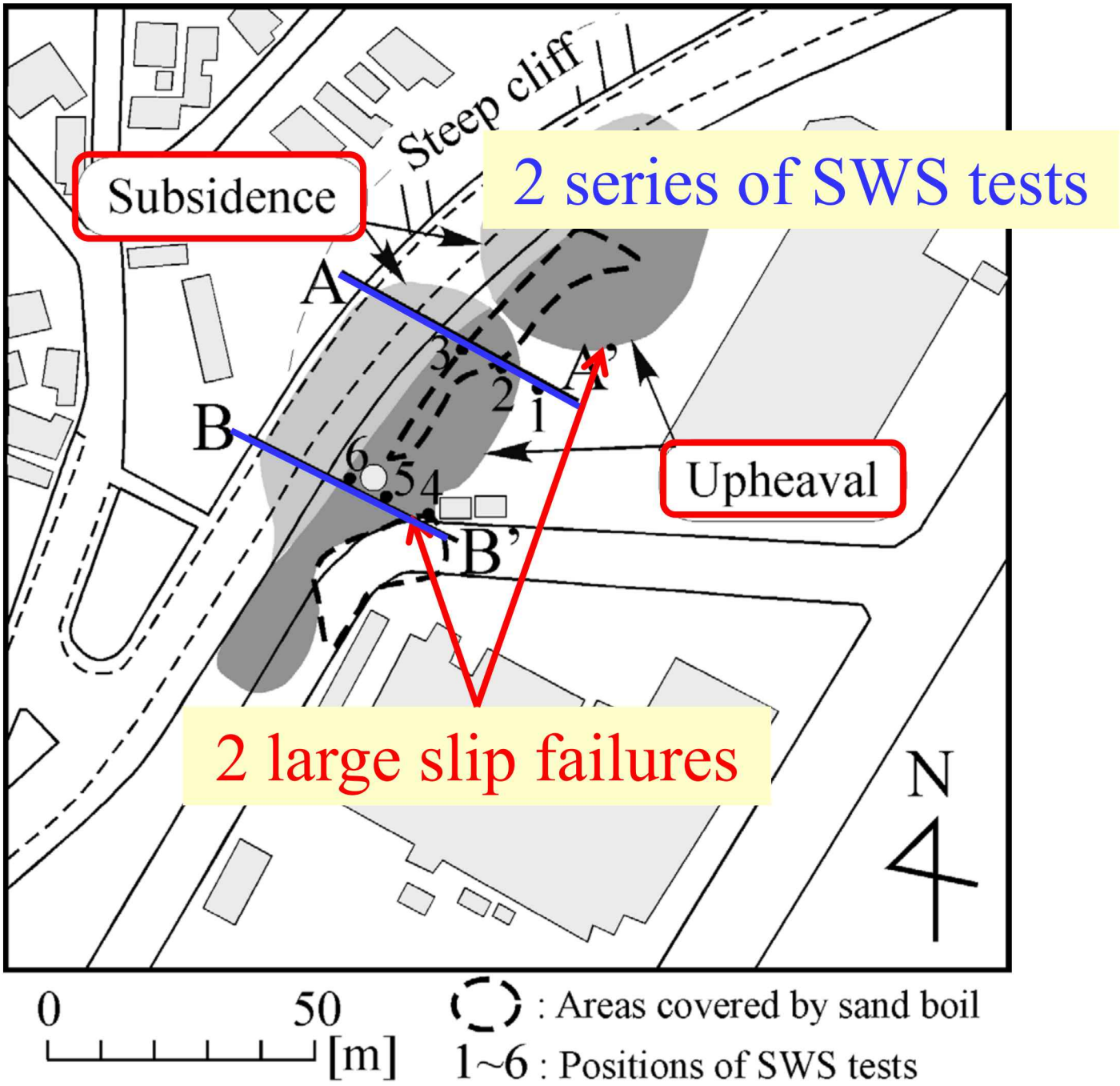


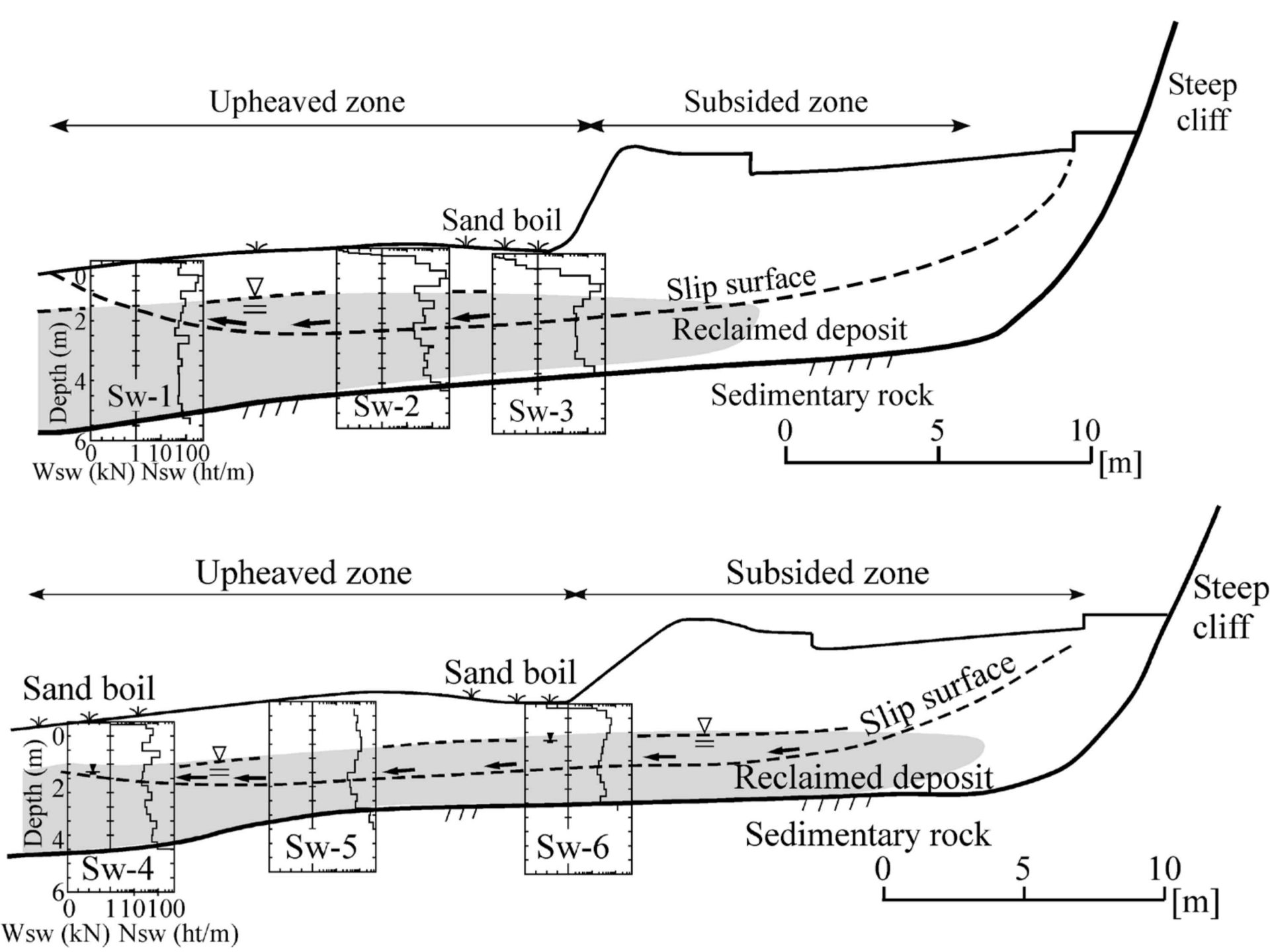

K-Net
Naka-minato
Steep cliff
Area of
reclamation
N
Nakagawa River
Naka-minato
Port
0
500
[m]

Route 173


K-Net
Naka-minato
Steep cliff
Area of
reclamation
N
Nakagawa River
Naka-minato
Port
0
500
[m]


茨城水産株式会社
那珂湊工場


Steep cliff
Subsidence
2 series of SWS tests
A
A'
B
B'
1
2
3
4
5
6
Upheaval
2 large slip failures
N
0
50
[m]
: Areas covered by sand boil
1~6 : Positions of SWS tests


Upheaved zone
Subsided zone
Steep cliff
Sand boil
Slip surface
Reclaimed deposit
Sedimentary rock
Depth (m)
Sw-1
Sw-2
Sw-3
Wsw (kN) Nsw (ht/m)
0 5 10 [m]
Upheaved zone
Subsided zone
Steep cliff
Sand boil
Sand boil
Slip surface
Reclaimed deposit
Sedimentary rock
Depth (m)
Sw-4
Sw-5
Sw-6
Wsw (kN) Nsw (ht/m)
0 5 10 [m]

Possible scenarios without eye-witness accounts (road embankment failures due to liquefaction of underlying reclaimed deposits)

(1) It is certain that soil liquefaction occurred within the reclaimed deposits beneath the road embankment during the main shock.

The collapse of the road embankment might have been induced

(2) during the main shock, due to the bearing loss in the underlying liquefied deposits,

or

(3) possibly during the aftershock, that occurred about 30 minutes after the main shock, due to the intensive seismic force, accompanied by the soil liquefaction in the underlying deposits.

Geotechnical issues unresolved

(1) Effects of duration of mainshock & aftershocks

The prolonged duration of seismic shaking obviously led to such far-reaching and outspread areas subjected to soil liquefaction, even at Tokyo bay areas, where the ground surface acceleration levels were relatively lower.

A number of aftershocks, particularly one of the largest aftershocks that occurred off the coast of Ibaraki prefecture about 30 minutes after the main shock, which might have further accelerated the occurrence of soil liquefaction and subsequent sand boil phenomenon.

It is known in geotechnical practice that as the earthquake magnitude is larger, the number of cycles of seismic shaking increases. Since the liquefaction resistance of soil is defined at a particular number of equivalent uniform stress cycles in laboratory triaxial tests, the liquefaction resistance would reduce in effect as the earthquake magnitude increases. The magnitude scaling factor represents such a reduction of the liquefaction resistance of soil with increasing earthquake magnitude, though it is not known whether it would also serve well for such a mega earthquake and its aftershocks.

(2) Ageing effects & re-liquefaction of soils

Most of the areas subject to soil liquefaction during this earthquake were found located at reclaimed lands, though some were found at natural soil deposits.

Here comes a great concern about how to evaluate ageing effects of soil on the occurrence of soil liquefaction.

Field penetration tests such as SWS and SPT would not reflect any ageing effects of soil on the penetration resistance, because they impose large strain to soil during penetration and hence are likely to rub out any trace of ageing regardless of its physical or chemical origin.

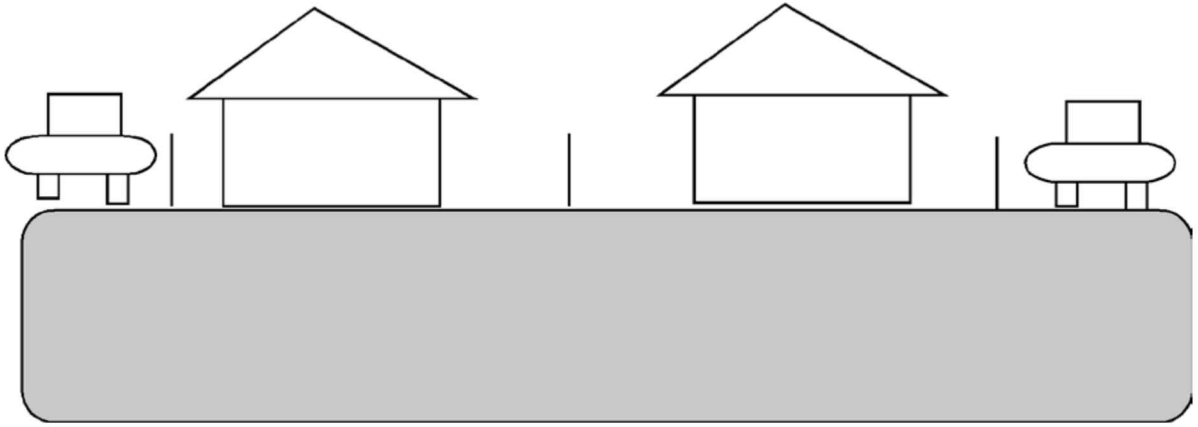
On the other hand, there are some "small-strain" field tests such as spectral analysis of surface waves (SASW), though it has been sometimes reported that those tests were also not able to detect any difference in the results between reclaimed and natural soil deposits.

Evaluating ageing effects of soil would be a crucial factor for determining the liquefaction resistance of soil for the coming foreseeable earthquakes.

Ongoing social projects

(1) Ministry of land, Infrastructure & Transport offered budgetary supports on liquefaction countermeasures for private land owners :

i.e. When the liquefaction countermeasures for private houses are undertaken together with adjacent infrastructures (roads) under some conditions, budgetary supports would be partially offered for private land owners.



(2) Given the budgetary supports from MLIT,
local city governments set up committees to see if such budgetary supports would be locally applicable, and if so, what kinds of liquefaction countermeasures would be locally effective.

Ongoing social projects

(3) Most of liquefaction countermeasures and associated machinery equipments have been developed for large-scale infrastructures.
Private construction companies are trying to develop effective small-scale & low-cost liquefaction countermeasures and equipments suitable for private houses.

i.e. lowering ground-water levels, cement jet grouting, etc.

(4) Legal system to check the probability of soil liquefaction for private houses, and associated engineering problems, i.e.
(a) use of low-cost & widely-used Swedish Weight Sounding tests for liquefaction evaluation
(b) development of any other field sounding tests for liquefaction evaluation
(b) probability of re-liquefaction for the scenario earthquakes