Geotechnical Preliminary Report of The M_j 7.3 Fukushima Earthquake on March 16, 2022

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Key Facts
- Hazard Type: Earthquake
- Date of the disaster: March 16th, 2022
- Location of the survey: Fukushima Prefecture and Miyagi Prefecture
- Date of the field survey: March 21st and 22nd, 2022
- Survey tools: Photos, videos, UAV, and LiDAR
- Key findings
  (1) Cracking, ground settlement, and ground deformation were observed in the roads, bridge approaches, and embankments in Fukushima Prefecture and Miyagi Prefecture
  (2) The landslides in Date Dam, Unoomisaki Tunnel portal area, and Tarumizu Dam could be associated with the strong ground motion of this earthquake event.
  (3) Liquefaction was also identified in Soma Port of Fukushima Prefecture.

Key Word: *The 2022 Earthquake off the coast of Fukushima Prefecture, Ground Damage, Slope Failure, Liquefaction*

1. INTRODUCTION

An intense earthquake of M_j 7.3 or M_w 7.4 (JMA, 2022) occurred on March 16th, 2022, off the coast of Fukushima Prefecture. The epicenter (37.697N, 141.621E) was about 60km deep. The maximum intensity observed was 6^+ on the JMA intensity scale in Tome City and Zao Town of Miyagi Prefecture, and Kunimi Town, Soma City, and Minami-Soma City of Fukushima Prefecture[1)].

The earthquake fault was located within the subduction zone of the Pacific Plate and subjected to a compressive field oriented in the east-southeast direction[2)]. Several earthquakes have similar fault rupture mechanisms, such as the earthquake on February 13th, 2021 (M_j 7.3) and April 7th, 2011 (M_j 7.2). However, the 2022 earthquake ruptured the fault plane in a northeast direction, which is different from the behavior of the two previous earthquakes.

The most significant peak ground acceleration PGA was 1232.7 gal at Kawasaki Seismic Station in Miyagi Prefecture (MYGH07) of the KiK-net strong-motion seismograph network[3)]. In addition, some other seismic stations in the surrounding area recorded an intense acceleration, such as Shinchi Town of Fukushima Prefecture and Yamamoto Town of Miyagi Prefecture. Furthermore, level 4 of the long-period ground motion scale of JMA was alerted in several cities in Miyagi Prefecture[4)].

This paper aims to summarize ground damage induced by the 2022 earthquake. The survey was conducted on March 21st and 22nd, 2022. The investigation locations are within the affected area in Fukushima Prefecture and the southern part of Miyagi Prefecture, as shown in **Fig.1**. Photos, videos, UAV, and LiDAR implemented on a mobile phone were used for the documentation.

2. DAMAGE IN FUKUSHIMA PREFECTURE

(1) Minami-machi, Yabuki Town

Fig.2 shows the damage on the shoulder of a local road next to a hotel facility, which stands over the Kumato River. Cracks or a cavity had developed over an area of 2m by 4m and were covered with blue sheets. Upslope of the ground settlement, there were traces of repaired works in the parking lot's pavement of the hotel. In addition, fresh soil could be seen in a hollow area on the downslope side. These suggest that the earthquake may have induced loosening of the cavity in the ground. Nevertheless, the UAV survey identified no significant deformation in the nearby bridge abutment or concrete revetment along the river.

(2) Dake Dam, Nihonmatsu City

A small-scale slope failure occurred on the steep slope along the Dake Walking Trail on the southern part of Dake Dam, as shown in **Fig.3**. The slope angle was about 60 degrees. The shotcrete facing the slope fell onto the path exposing the partially weathered mudstone behind. The geological map of AIST[5] shows that the local surficial geology of the adjacent area is classified as granite formed during the Cretaceous Period. Granite can lose its stiffness due to weathering because it contains compositional minerals with different coefficients of thermal expansion[5]. Therefore, the shear resistance of the weathered mudstone was possibly exceeded by the sliding force during the earthquake event, causing shallow failure on the slope.

(3) Tohoku Shinkansen viaduct, Kunimi Town

One Tohoku Shinkansen viaduct pier at 15km northeast of Fukushima Station suffered from tilting after the earthquake. The pier inclined towards the direction of the Shiroishizao Station. The lower part of the viaduct showed a typical shear failure; the failure of the cover concrete and buckling of the axial reinforcement bars, based on the preliminary report from the East Japan Railway Company[7]. The direct cause of the shear failure can be attributed to the insufficient

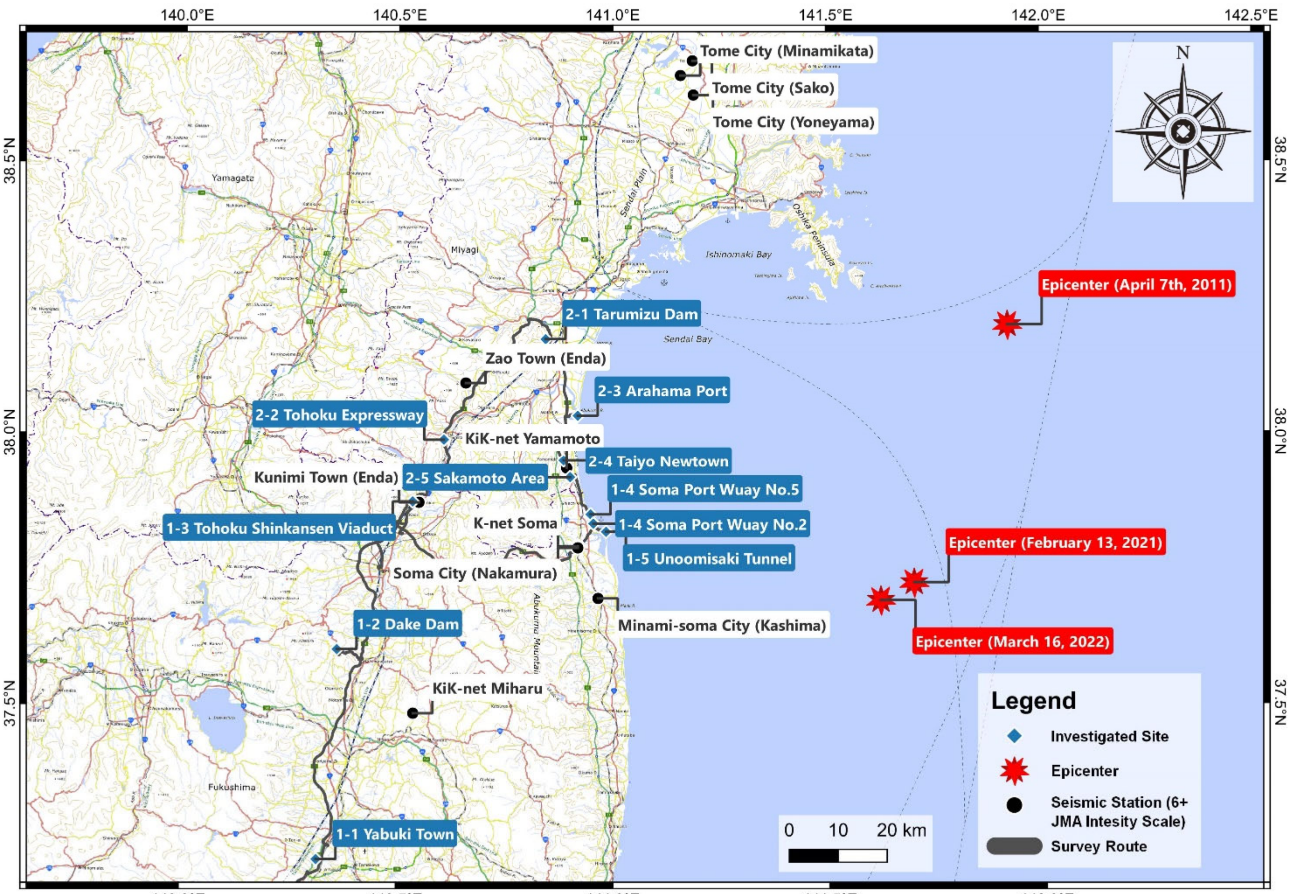

Fig.1 Survey route, investigation sites, the epicenter of the earthquakes on March 16th, 2022, February 13th, 2021 and April 7th, 2011, and the seismic stations that recorded 6+ on the JMA intensity scale

shear strength of the pier because no land subsidence was observed around the pier. As shown in **Fig.4**, restoration works have been in progress to realign the harmed pier when our team arrived

The Active Fault Map from the Geospatial Information Authority of Japan (GSI)[8] shows the damaged pier locates on the alluvial plain of the Takigawa River, neighboring a higher terrace in the southeast (**Fig.5**). The higher terrace on the downstream of the Takigawa River has been lifted up because of two reversal faults called Fujita East Fault and Fujita West Fault. These liftings could change the flow direction of the Takigawa River and might result in depositing a loose and soft sedimentary layer around the affected site.

Fig.6 shows the absolute inclination angle of the catenary poles near the site, based on a 3D model created from the sequential images of the UAV[9]. The pole above the inclined pier was named CP_8. The suffix number decreases as the pole is located west-southward. CP_5 is almost above the boundary between a lower terrace and the alluvial plain of the Takigawa River. **Fig.6** indicates that the angle of the poles near the boundary is larger than one in other areas. Although other factors such as pier length or steel lining may affect the pole behavior, the difference in the inclination angle implies the local topography changing the damage characteristics.

(4) Soma Port Quay No. 2 and No. 5

At Soma Port, ground settlement of approximately 0.5 m to 1 m was recorded at Quay No. 2, as shown in **Fig.7**. The 5m-thick quay wall concrete block has moved towards the sea by about 20 cm to 30 cm. A small amount of boiled sand was observed in the gap between the quay wall and the settled ground in the southeastern corner, in which liquefaction also happened in the 2021 Fukushima Earthquake. A simple sieve analysis was carried out with the sand ejecta to obtain the particle gradation curve. **Fig.8** indicated that D_{50} of the sample is 0.15 mm, and the curve was within the range particularly prone to liquefaction based on the guideline from MLIT[10]. A similar deformation pattern was observed at Matsukawaura New Fishing Port, located southeast of Soma Port. In addition, extensive cracks with a length of 85m-100m and an opening size of about 30cm, parallel to the quay wall, occurred at about 14m from the quay wall. The resulting damage was similar to that caused by the 2021 Fukushima Earthquake[11].

At Quay No .5, a 130m-long crack was recorded on the carriageway (**Fig.9(a)**). There were small steps on the cracked road due to settlement. A slight displacement between seawall panels was also identified. Another implication of the earthquake was the destruction of two of the four coal unloading machines installed at Quay No. 5, as shown in **Fig.9(b)**. This destruction has halted the operation of the Shinchi Thermal Power Station, severely affecting the electricity supply in the service area of Tokyo Electric Power Company (TEPCO) on March 22^{nd}, 2022.

Fig.2 Cracked and subsided area in Yabuki Town of Fukushima Prefecture **(a)** Whole view, **(b)** Subsided area of 2m by 4m, **(c)** Backfilled area in the parking lot

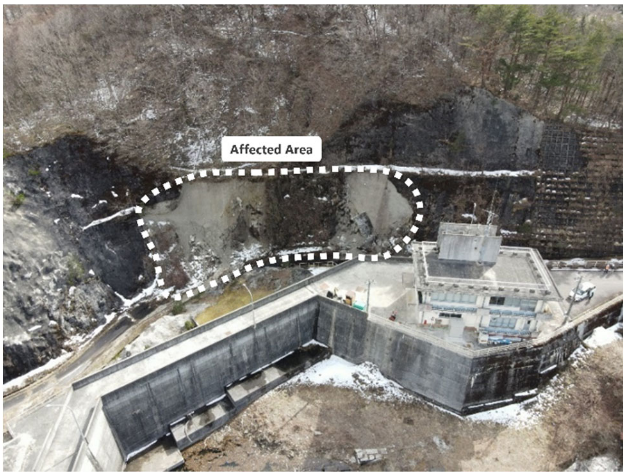

Fig.3 Small slope failure on the steep slope along the Dake Walking Trail

Fig.4 Inclined pier of Tohoku Shinkansen viaduct in Kunimi Town

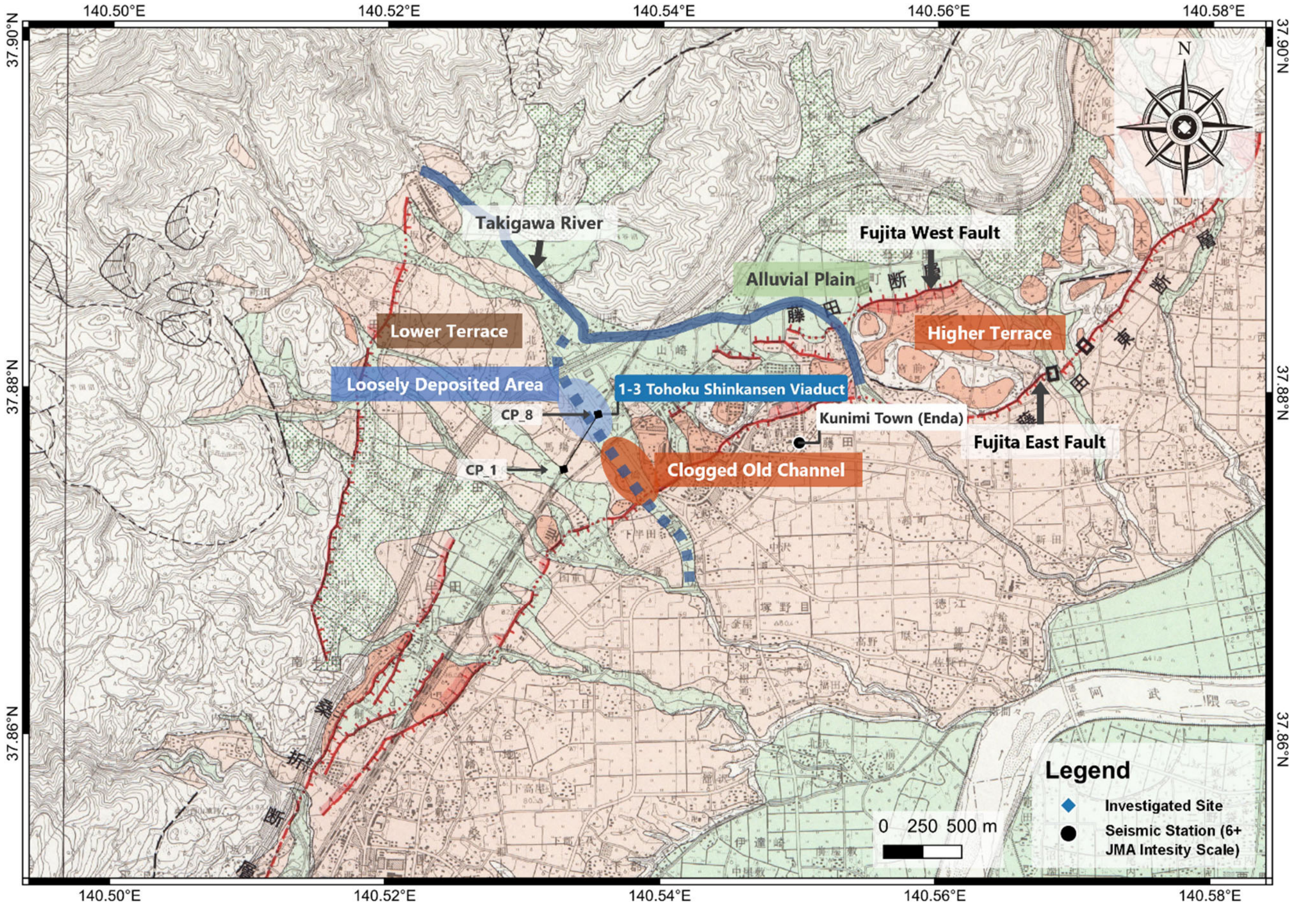

Fig.5 Local topography map around the damaged viaduct in Kunimi Town based on the Active Fault Map[8)]

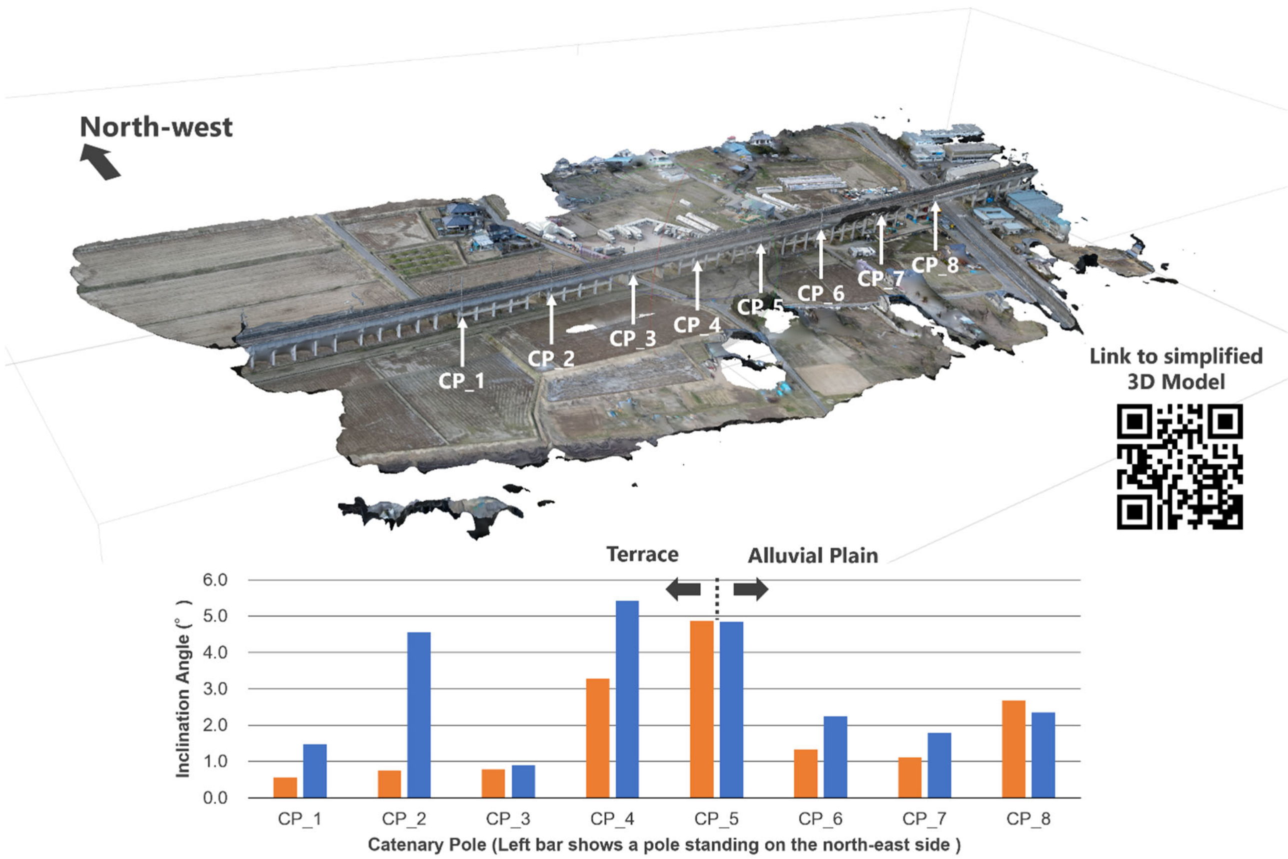

Fig.6 Absolute inclination of the catenary poles in the adjacent area. The decimated 3D model is available[9)]

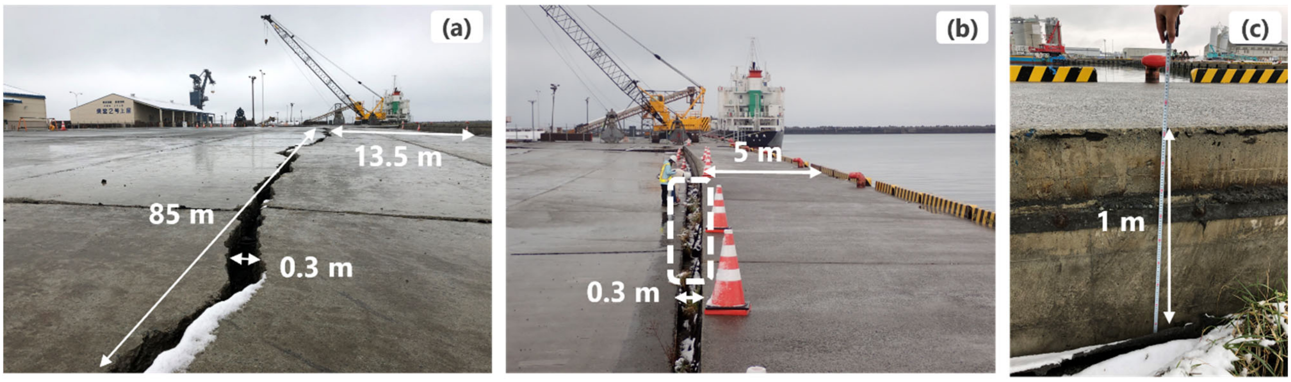

Fig.7 Cracks between the quay wall blocks

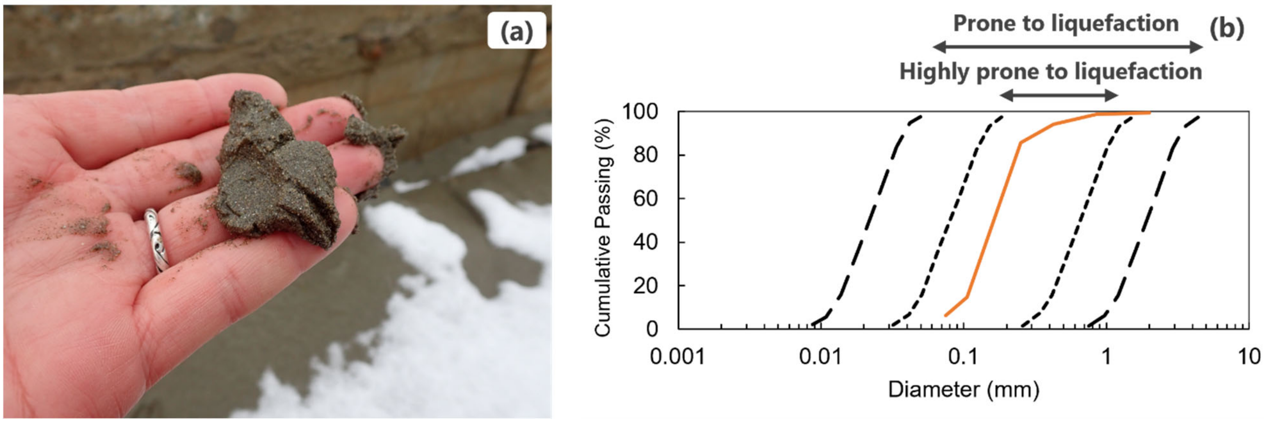

Fig.8 (a) Sand ejecta taken from a quay wall block, **(b)** Particle distribution curve and the diameter range of sand prone to liquefaction

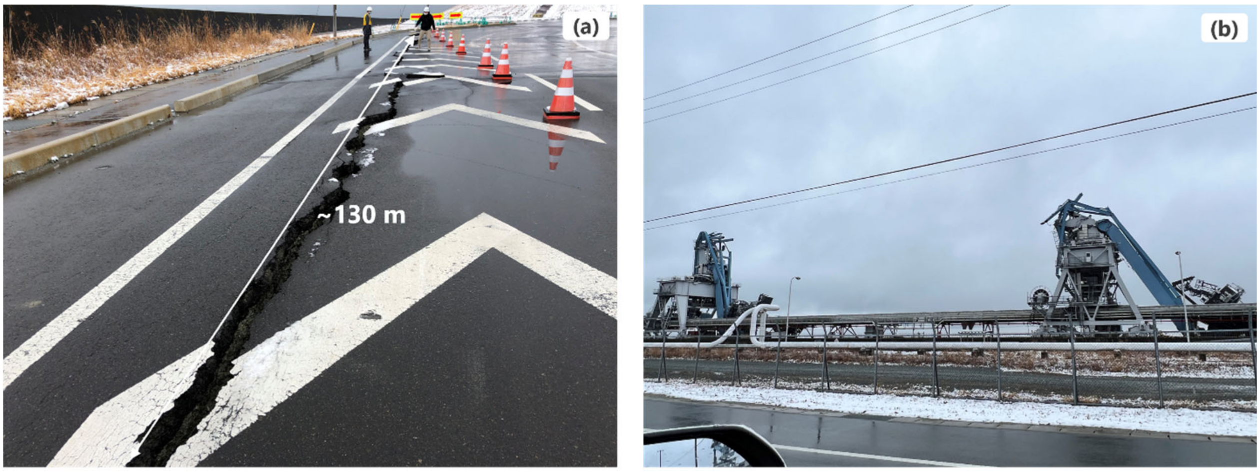

Fig.9 (a) a 130m-long crack on the carriageway in Quay No. 5, **(b)** Coal unloading machine with ruptured transverse beam

(5) The tunnel portal of Unoomisaki Tunnel near the Matsukawa-ura Bridge

Rock slope failure was triggered by the earthquake at the northern side of the tunnel portal of Unoomisaki Tunnel along the 2-lane carriageway of Matsukawaura Bridge, as demonstrated in **Fig.10**. From the 1:50,000 Geological Map of the Soma-Nakamura District, this region is composed of greenish-gray mudstone (D2) of the Pliocene Dainenji Formation[12]. With the observation of some several cm thickness sandstone layers, the bedding plane orientation in this area is almost horizontal. The slope is prone to rockfall failure because it is divided by multiple vertical joint sets. Rockfalls could have taken place following the vertical joints that are orange-brown and show significant signs of chemical weathering brought by seepage. The rock boulders were as large as 5 m wide. Collapsed electricity poles, rock and surface soil debris, and pine trees on top of the cliff blocked a small part of the carriageway (**Fig.10 (a)**). The extent of the rockfall was estimated to be about 15 m in breadth.

Saito et al.[13] reported a similar rockfall slope failure occurred 300 m west of the 2021 earthquake. Osumi et al.[14] conducted a series of biochemical analyses and pointed out chemical weathering by microorganisms as the predisposing cause of the collapse.

3. DAMAGE IN THE SOUTHERN PART OF MIYAGI PREFECTURE

(1) Tarumizu Dam, Natori City

A massive landslide was inspected along the road leading from the top-left water dam and the dam office (**Fig.11**). The landslide debris of shotcrete, rock, mud, and trees entirely blocked the 4m-wide road. The debris mass continued to run out downslope to the top part of the spillway structure overlooking the Masuda River. The average slope inclination was between 50 degrees and 60 degrees. The crest of the scarp area was located about 25 m high from the road level. The width and depth of the landslide were about 20 m and 1 m, respectively. The failed section was of the largest height compared to the adjacent slope reinforced by shotcrete. The collapsed soil mass mainly comprises brown, slightly weathered gravels.

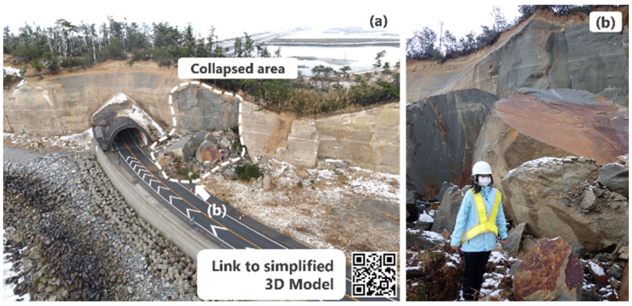

Fig.10 Rock failure at the northern side of the tunnel portal of Unnomisaki Tunnel **(a)** Whole view, **(b)** Fallen rock

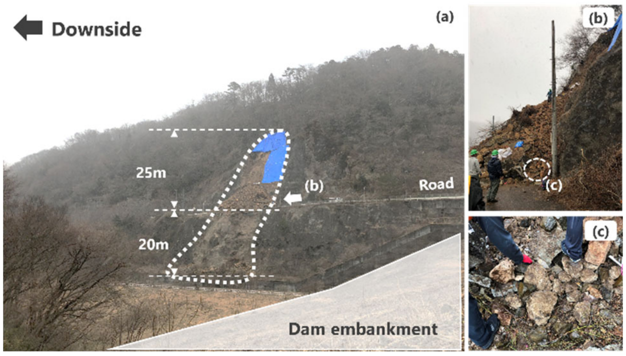

Fig.11 Steep landslide at the downside of Tarumizu Dam **(a)** Whole view, **(b)** debris crossing the road, **(c)** partially weather rock in the debris

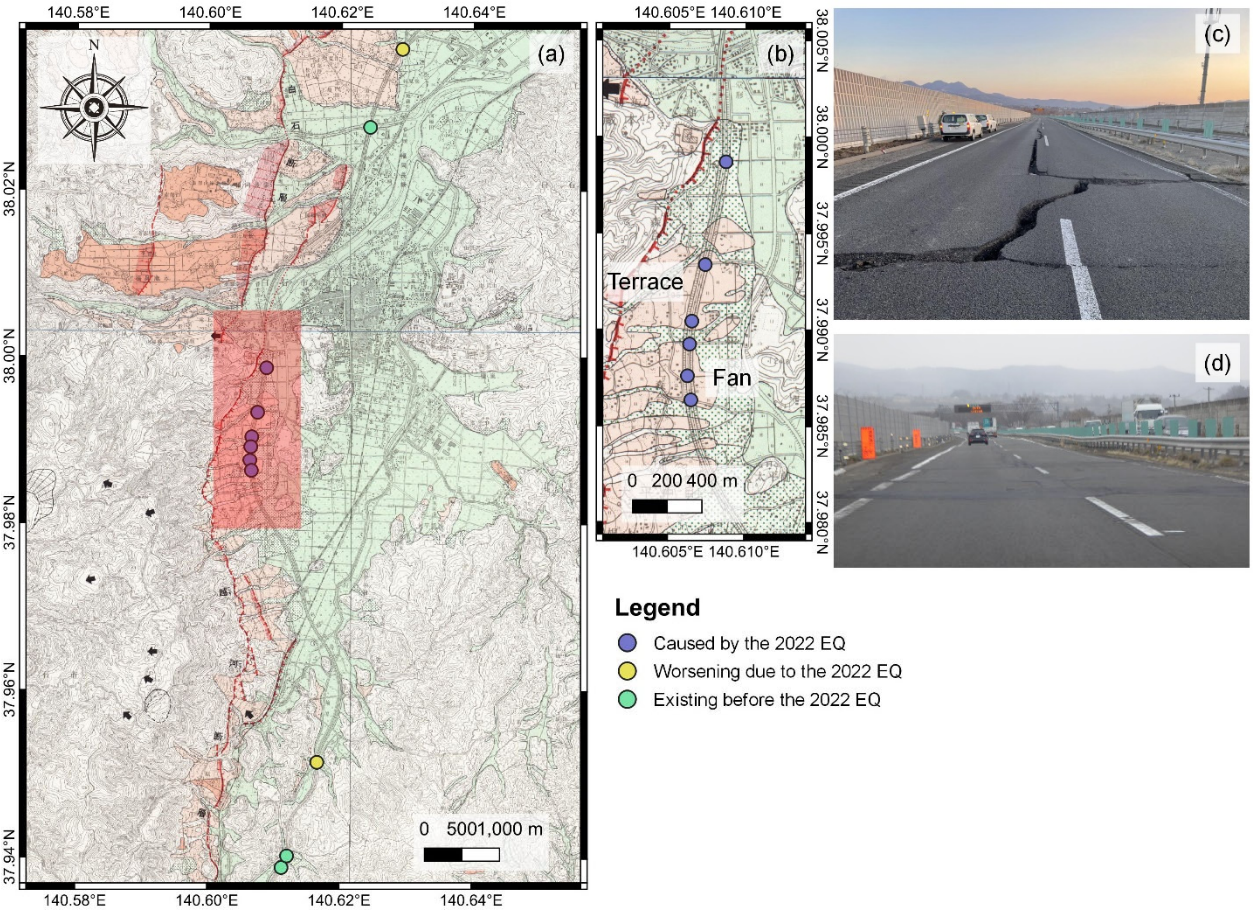

Fig.12 Cracks distribution appeared in the section from Kunimi to Shiraishi of Tohoku Expressway **(a)** Whole Map, **(b)** enlarged map, **(c)** captured cracks by NEXCO[15] soon after the earthquake, **(d)** repaired pavement on April 23rd

(2) Tohoku Expressway in Shiroishi City

The Tohoku Expressway was affected by moderate ground cracking and settlement associated with the 2022 Fukushima Earthquake (**Fig.12**). Many bumps were present during a brief survey driving north on the Tohoku Expressway. An approximately 50 m long retaining wall seems to have been damaged as it was under immediate recovery works.

By comparing the observations from the reconnaissance survey against Google Street View as of August 2021, a preliminary analysis of the distribution of ground cracking was carried out. As presented in **Fig.12**, cracks induced by this 2022 earthquake were identified at localities marked by blue dots. Yellow dots indicate cracking locations that propagate after the ground shaking, while glay dots are locations with existing cracks. The new cracks occurred mainly in the vicinity of the boundary between the box culvert and embankment regions. They are also concentrated on the western side of Shiroishi City, for instance, near Box Culvert Kunimi 65, 66, 67, 69, 71, and 75.

(3) Arahama Fishing Port, Watari District

Slight ground surface damages were observed in the vicinity of Arahama Fishing Port. For example, a crack was found at the bottom of an electric pole near a hotel (**Fig.13**). In addition, some cracks and ejecta in the Torinoumi Park close to the sea wall have been identified by a resident, as shown in **Fig.14(a)**. Wakamatsu[15] found a similar pattern of sand ejecta and ground fissure after the 2021 earthquake at the same location (**Fig.14(b)**) and indicated that the liquefied area is located near a shoreline in the latest reclaimed area of the port.

(4) Taiyo Newtown, Yamamoto Town, Watari District

The damage conditions in the residential embankment area of Taiyo Newtown in Yamamoto Town were examined as significant ground deformation in the 2011 Tohoku Earthquake. While cracks of 10 cm to 20 cm in width could be identified on a slope along the road connecting to the National Route 6 (**Fig.15**), less critical geotechnical damage was brought by the 2022 earthquake than by the 2011 earthquake.

(5) Sakamoto, Yamamoto Town, Watari District

The inspection was made around the Disaster Prevention and Communication Center of Yamamoto Town. Cracks and ground settlement could be observed in the surrounding area of the Center (**Fig.16**). On the National Route 6 in the Sakamoto area, the ground settled mildly, and a crack of about 30 m long was being repaired; in a nearby petrol station, there seems to be uplift in the surface drainage channel. Our previous survey[11] after the 2021 earthquake revealed building structures in the area that suffered from damages were those constructed before the 2011 earthquake, while the ground was damaged in the areas reclaimed after the 2011 earthquake. A similar pattern was observed after the 2022 earthquake (**Fig.16**).

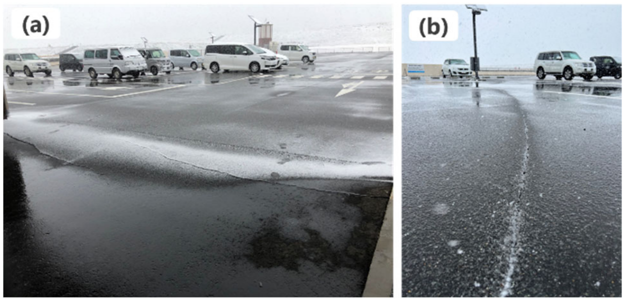

Fig.13 Cracks on the pavement of the parking lot ot a hotel

Fig.14(a) Sand ejecta after the 2022 earthquake captured by Mr. aito, a local resident, **(b)** sand ejecta after the 2021 earthquake at the same location[15]

4. CONCLUSION

Different manifestations of geotechnical damage due to the 2022 Fukushima earthquake have been investigated in this survey. Cracking, ground settlement and deformation were observed in the roads, bridge approaches and embankments. The landslides in Date Dam, Unoomisaki Tunnel portal area and Tarumizu Dam could be associated with the strong ground motion of this earthquake event. Liquefaction was also identified in Soma Port of Fukushima Prefecture.

Fig.15 Ground deformation of the slope of Taiyo Newtown **(a)** after the 2011 earthquake, **(b)** after the 2022 earthquake, **(c)** uneven deformation, **(d)** cracks on the embankment

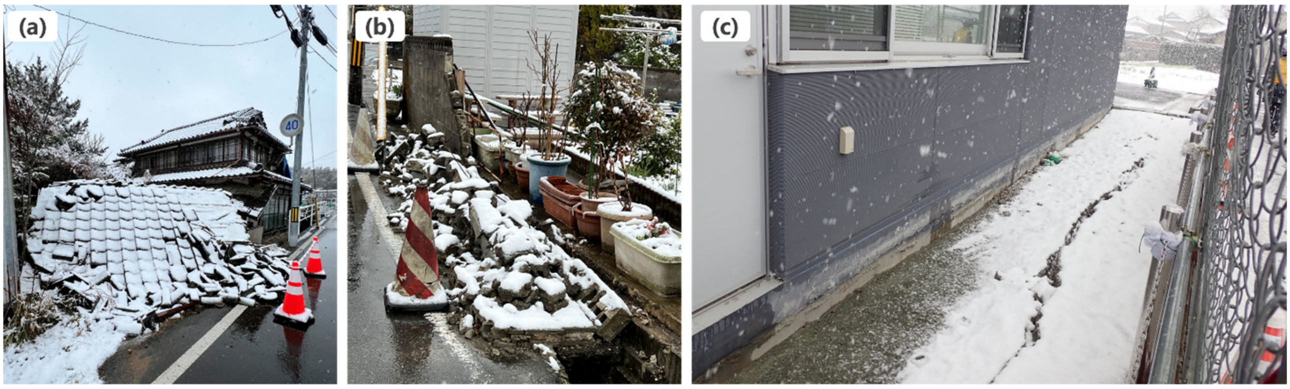

Fig.16 **(a)** Collapsed house (old residential area), **(b)** collapsed concrete-block wall (old residential area), **(c)** ground crack in the vicinity of the Center (newly landfilled area)

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REFERENCES

1) Japan Meteorological Agency: Earthquake Information: Detail Information, https://www.data.jma.go.jp/multi/quake/quake_detail.html?eventID=20220317001109&lang=jp (Accessed April 13, 2022)

2) Goto, H., Kurima, J., and Anirban, C.: Field survey on the earthquake off the coast of Fukushima Prefecture on March 2022, http://wwwcatfish.dpri.kyoto-u.ac.jp/~goto/eq/20220316/report.pdf (Accessed April 13, 2022)

3) National Research Institute for Earth Science and Disaster Prevention: Strong ground motion caused by the earthquake off the coast of Fukushima Prefecture on March 16, 2022, https://www.kyoshin.bosai.go.jp/kyoshin/topics/html20220316233630/main_20220316233630.html (Accessed April 13, 2022)

4) Japan Meteorological Agency: Observation information on long-period seismic motions, https://www.data.jma.go.jp/svd/eew/data/ltpgm_explain/data/past/20220316233646/index.html (Accessed April 13, 2022)

5) National Institute of Advanced Industrial Science and Technology: 1:50,000 scale geological map (Nihonmatsu), https://www.gsj.jp/data/50KGM/JPG/GSJ_MAP_G050_07033_1995_200dpi.jpg (Accessed April 13, 2022)

6) Goudie A. S., Allison R. J., and McLaren S. J.: The relations between modulus of elasticity and temperature in the context of the experimental simulation of rock weathering by fire, *Earth Surface Processes and Landforms*, Vol.17, No. 6, pp. 605-615, 1992.

7) Inoue, K. and Uemura K.: Report on the structural damage investigation of the earthquake off the coast of Fukushima Prefecture on March 16, 2022,

https://committees.jsce.or.jp/eec2/system/files/20220330_福島沖の地震被害調査報告(井上 植村）.pdf (Accessed April 13, 2022)
8) The Geospatial Information Authority of Japan: Map of active fault, https://maps.gsi.go.jp (Accessed April 13, 2022)
9) Shiga, M.: Damaged piers of Tohoku Shinkansen in Fukushima, https://skfb.ly/otODP (Retrived April 13, 2022)
10) Ministry of Land, Infrastracture, Tranportation and Tourism: Technical Standards for Port Facilities and Commentary, 2007
11) Inoue K., Kiyota T., Shiga, M., Dang, J., and Wang, X.: Preliminary Report of the Damage by the 2021 Off Fukushima Prefecture Earthquake Mj7.3, Japan, *JSCE Factsheet*, 2021
12) National Institute of Advanced Industrial Science and Technology: 1:50,000 scale geological map (Soma-Nakamura), https://www.gsj.jp/data/50KGM/JPG/GSJ_MAP_G050_07025_1996_200dpi.jpg (Accessed April 13, 2022)
13) Saito, M., Watanabe, M., and Yanagisawa, Y.: Geological features of the collapsed area in Soma City, Fukushima Prefecture, caused by the earthquake at 23:07 on February 13, 2021, https://www.gsj.jp/hazards/landslide/20210213-disaster.html (Accessed April 13, 2022)
14) Osumi, T., Mizui, Y., Ikeda M., and Matsubara, H.: A Study of Slope Damage in Matsukawaura, Shinchi Town, Shiogama City Related to the 2021 Fukushima Offshore Earthquake and the 2021 March Miyagi Offshore Earthquake, *Natural Disaster Research Report of NIED*, Vol.59, pp. 29-40, 2022.
15) NEXCO East Japan (Tohoku), https://twitter.com/e_nexco_tohoku/status/1504227495989571585 (Accessed April 13, 2022)
16) Wakamatsu, K,: Geo-disaster and Liquefaction due to the earthquake off the coast of Fukushima Prefecture on February 13th, 2021, https://www.jaee.gr.jp/jp/wp-content/uploads/2021/02/210213narui_wakamatsu.pdf (Accessed April 13, 2022)

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