MARCH 16, 2022 M7.3 FUKUSHIMA EARTHQUAKE GEOTECHNICAL DAMAGE SURVEY

Kwok-Kwan LAU[1], Pei-chen HSIEH[1], Masataka SHIGA[2] and Takashi KIYOTA[3]

ABSTRACT:

In this survey, the damages brought by the March 16, 2022 Off Fukushima Earthquake to the infrastructure and geotechnical structures in Fukushima and Miyagi Prefecture were inspected. Minor liquefaction was found at Soma Port. Ground deformation and cracks were examined at various locations including Date Bridge, Tohoku Shinkansen viaduct in Kunimi Town and coastal towns in Watari and Yamamoto of Miyagi Prefecture. The report also summarizes the landslide occurrence in Dake Dam, Unoomisaki Tunnel and Tarumizu Dam.

Key Words: *March 2022 Fukushima Earthquake, Liquefaction, Landslide, Ground Settlement*

INTRODUCTION

A strong earthquake of moment magnitude 7.3 struck Japan off the coast of Fukushima Prefecture on March 16, 2022, at 23:36 JST. The epicenter (37.7N, 141,7E) was about 60 km deep, and the maximum seismic intensity recorded was 6+ in Tome City and Zao Town of Miyagi Prefecture, and Kunimi Town, Soma City and Minami-Soma City of Fukushima Prefecture (Japan Meterological Agency, 2022). The earthquake has been described to be initiated by a reverse fault within or near the subduction zone plate boundary of the Pacific and North America plates, characterized by the compression axis oriented in the east-southeast direction as expected for this region (USGS, 2022). Referring to the acceleration record in Figure 1, the largest peak ground acceleration PGA was measured as 1232.7 gal at Kawasaki Station, Miyagi Prefecture (MYGH07) of the KiK-net strong-motion seismograph network (NIED, 2022).

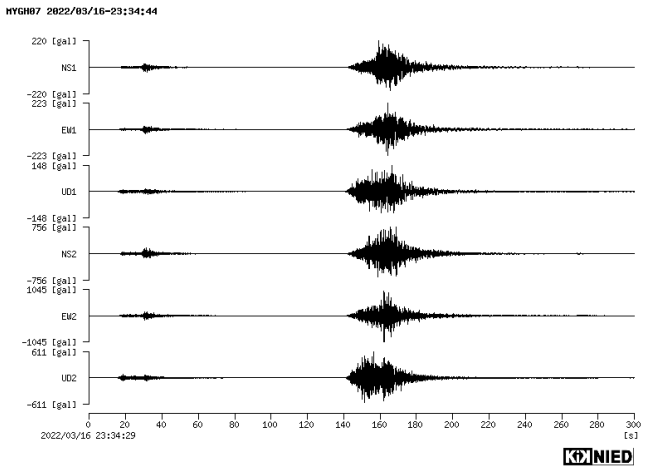


Figure 1. Acceleration records at MYGH07 Station (NIED, 2022)

[1] Graduate Student, Dept. of Civil Eng. University of Tokyo
[2] Assistant Professor, Institute of Industrial Science, University of Tokyo
[3] Associate Professor, Institute of Industrial Science, University of Tokyo

A previous large ground shaking in the affected areas was the February 13, 2021 M 7.3 Off Fukushima Prefecture Earthquake which has been believed to be an aftershock of the M 9.1 2011 off the Pacific coast of Tohoku Earthquake. Compared with the 2021 event, the faulting mechanism is understood to bear resemblance; the epicenter of the 2022 earthquake is closer to the coast and slightly shallower, for the 2021 earthquake epicenter depth is about 64.7 km (Inoue et al., 2021).

One major incident triggered by the March 2022 Fukushima earthquake was the derailment of a high-speed Shinkansen train travelling between the Fukushima Station and Shiroishizao Station, leading to suspension of train services. Other infrastructure such as Tohoku Expressway and port facilities in Fukushima and Miyagi Prefectures have been reported to display various degrees of ground damage after the quake (MLIT, Japanese Government, 2022).

After collating damage information from various governmental bodies, the media, social networking sites, past earthquake reports and instant updates from other researchers, our investigation team attempted to verify the damage conditions and selected a number of affected sites for the damage survey. The aims of this survey were to investigate the geotechnical earthquake damages in Fukushima and Miyagi Prefecture, and to compare the impacts with past disasters. Particular attention was paid to examine whether re-liquefaction has occurred in locations with liquefaction histories.

SURVEY AREA AND METHOD

The damage survey was carried out on March 21 and 22, 2022. The investigation route and sites in Fukushima and Miyagi Prefecture are provided in Figure 2. The inspected sites were mainly in the region of Koriyama City and Fukushima City of Fukushima Prefecture, Shiroishi City of Miyagi Prefecture, and the coastal area adjoining the two prefectures. Photos and video records were taken with digital cameras and drone.

Figure 2. Route and inspection sites

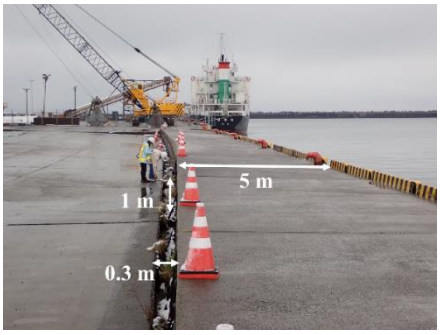
DAMAGES IN FUKUSHIMA PREFECTURE

Liquefaction in Fukushima

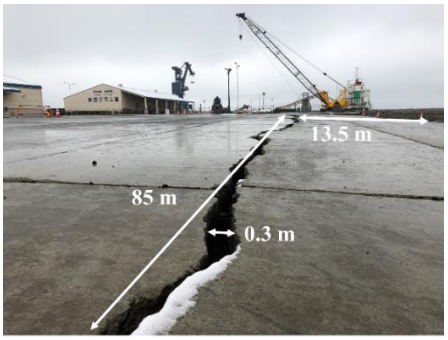
Soma Port Quay No. 2 (37°50'19.2"N, 140°57'17.4"E) and No. 5 (37°51'18.9"N, 140°56'54.7"E)

At Soma Port, ground settlement of approximately 0.5 m to 1 m was recorded at Quay No. 2 as shown in Figure 3a and 3c. 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, as can be appreciated in Figure 2c, was observed in the gap between the quay wall and the settled ground in the southeastern corner, at which liquefaction also happened in the 2021 Fukushima Earthquake. Extensive cracks developed parallelly to the shore at about 14 m away from the quay wall, with a length of 85 m to 100 m and an opening size of about 30 cm. The resulting damage was similar to that caused by the 2021 Fukushima Earthquake (Inoue et al., 2021).

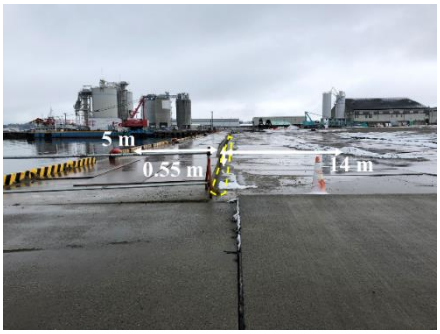
At Quay No .5, a 130m-long crack was recorded on the carriageway (See Figure 3e). There were small steps on the cracked road due to settlement. Slight displacement between seawall panels was also identified. Another implication of the earthquake was the destruction to two of the four coal unloading machines installed at Quay No. 5 as shown in Figure 3f. This 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, 2022.



(a) Deformation at Quay No. 2



(b) Crack on the ground at Quay No. 2



(c) Liquefaction at Quay No.2

(d) Close up of the crack in (c)

(e) Crack in the road at Quay No. 5

(f) Damaged coal unloading machine

Figure 3. Damages at Soma Port

Ground settlement in Fukushima

<u>Minamimachi, Yabuki Town, Nishishirakawa District (37°13'10.4"N, 140°18'57.2"E)</u>

The ground settlement in Minamimachi of Yabuki Town was inspected. The damage occurred at the shoulder of a local road next to a hotel facility, which stands over the Kumato River. The subsided area was about 1.5 m perpendicular to the slope crest and 2 m long along the road as shown in Figure 4. Upslope of the ground settlement, there were traces of repaired works in the carpark pavement of the hotel. Fresh soil could be seen in a hollow area in the downslope side. These suggest that cavity may be present in the ground. At the northern end of the road, cracks of 10 cm wide were found at the slope crest and on the road. At this location, the ground had settled and displaced towards the river under the ground shaking. Nevertheless, no major deformation was identified in the embankment from the drone survey.

Figure 4. Ground settlement in Minamimachi

Slope failure in Fukushima

<u>Dake Dam, Nihommatsu City (37°36'22.5"N, 140°21'41.4"E)</u>

A small-scale slope failure occurred on the steep slope along Dake Walking Trail on the southern part of Dake Dam. The slope angle was about 60 degrees. The shotcrete facing of the slope fell onto the path exposing the mudstone behind. It is possible that the shear resistance of the weathered mudstone was exceeded by the sliding force during the earthquake event, causing shallow failure on the slope.

Figure 5. Landslide next to Dake Dam

Rockfall near the tunnel portal of Unoomisaki Tunnel near the Matsukawa-ura Bridge (37°49'25.5"N 140°59'04.5"E)

Rock slope failure was triggered by this Fukushima earthquake at the northern side of the tunnel portal of Unoomisaki Tunnel along the 2-lane carriageway of Matsukawa-ura Bridge as demonstrated in Figure 6a. From the 1:50,000 Geological Map of the Soma-Nakamura District, this region is composed of greenish gray mudstone (D2) of Pliocene Dainenji Formation (Geological Survey of Japan, AIST, 1996). With some layers of sandstone, this formation displays horizontal beddings, and the ground is prone to slope failure as can be observed from the presence of multiple joint sets. Rockfalls could be seen to have taken place following the vertical joints which are orange-brown and shows significant signs of chemical weathering brought by seepage. The rock boulders were as large as 5 m wide. Debris of damaged electricity poles, rock, surface soil and pine trees which were on top of the cliff blocked a small part of the carriageway (see Figure 6b). The extent of the rockfall was estimated to be about 15 m in breadth.

(a) Overview

(b) Debris

Figure 6. Rockfall near Unoomisaki Tunnel Portal

Damage to infrastructure in Fukushima

Date Bridge, Date City (37°49'11.3"N, 140°30'37.8"E)

The 2022 Fukushima Earthquake caused large damage to the 4-span continuous truss Date Bridge. The bridge displacement was approximately 25 cm towards to the west. During the ground shaking, the deck was compressed at the western abutment, and it was detached from the east abutment as shown in Figure

7a and 7b. Some water pipes and electricity cables below the bridge girder were deformed. Dislocation could be observed in the support connections in the piers (Figure 7c). Traffic has been blocked since the earthquake event.

On the other hand, the old, pedestrian Date Bridge, which is of simple truss structure survived the earthquake, showing minor damages only. Small relative displacements could be found between the individual trusses. At different locations, the barriers have showed some degree of deformations which give signs of compression or extension.

(a) West abutment

(b) East abutment

(c) Displacement in pier supports

(d) Date Bridge on the right and the old bridge on the left

Figure 7. Destruction to Date Bridge

Tohoku Line Overpass Bridge in Kasaishi, Kagamiishi Town, Iwase District (37°14'43.6"N, 140°20'33.8"E)

Various forms of damage could be identified in the Kasaishi Tohoku Line Overpass. Fault movement could have caused the steps that were seen in the connection joints between the retaining walls. There were also deformations in the hand railing and barrier. No significant crack was observed on the road pavement in the meanwhile. The Overpass Bridge suffered damages from the previous 2021 earthquake (Abukumajiho, 2021), with cracks appearing in the embankment of Pier P6 and P7. Although several rubber joints were seen popping out, no new damage to the embankment section was visible after the 2022 earthquake.

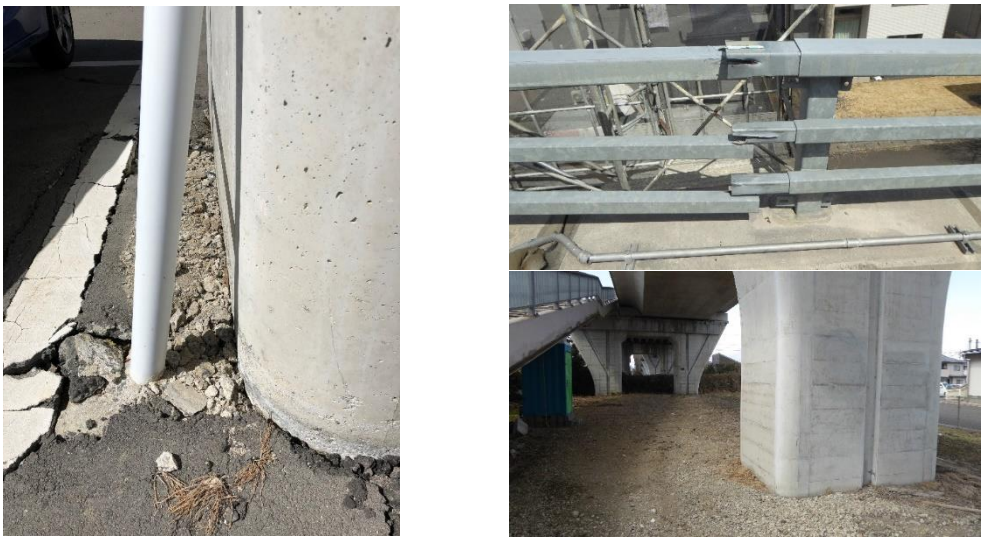


Figure 8. Damages in the Kasaishi Tohoku Line Overpass

Dake Onsen Line, National Route 459 and Dake Onsen Shrine (37°36'25.3"N 140°21'17.7"E), Nihommatsu City

While there was traffic control imposed to the Dake Onsen Line, probably in consideration of the ongoing slope works, no slope failure was spotted in this area of Route 459. Leaving the Dake Onsen Line, the investigation team stopped at the Dake Onsen Shrine. As can be seen from Figure 9, dislocation of the connecting part of the beam of the Torii gate was noted. There were stone lanterns fallen as well.

Figure 9. Dake Onsen Shrine

Tohoku Shinkansen viaduct, at the crossing with Fukushima Prefecture Route 46 in Kunimi Town, Date District (37°52'43.3"N, 140°32'07.6"E)

South of the Shiroishizao Station, one Tohoku Shinkansen viaduct pier suffered from tilting after the earthquake. The pier inclined towards the direction of the Shiroishizao Station. Based on the landform information from the Geospatial Information Authority of Japan (GSI), the damaged pier locates on the alluvium plain of Takigawa River, neighboring a terrain plain in the southwest. There could be old river channel underneath in this area, where soft deposit may be present. Based on the immediate inspection report of the East Japan Railway Company (JR East, 2022), no land subsidence was observed around the pier. Shear failure at the base of the pier could have triggered the tiling. As shown in Figure 10, restoration works has been in progress as to realign the harmed pier.

Figure 10. Damaged pier of the Tohoku Shinkansen viaduct

DAMAGES IN MIYAGA PREFECTURE

Ground surface damage in Miyagi

Arahama Port, Watari District (38°02'17.6"N, 140°55'03.0"E)

Slight ground surface damages (Figure 11) were observed in the vicinity of Arahama Port. For example, a crack was found at the bottom of electric pole near a hotel. As can be observed in Figure 13a, cracks with opening up to 15 cm stretched in the Torinoumi Park close to the sea wall. From a previous report (Wakamatsu, 2021), multiple sand ejecta were found from the 2021 earthquake at the same location, and some ejecta have been identified at similar locations by a local resident as shown in Figure 13b and 13c.

Taiyo Newtown, Yamamoto Town, Watari District (37°57'19.4"N, 140°53'08.3"E)

The damage conditions in the residential embankment area of Taiyo New Town in Yamamoto Town were examined as significant ground deformation was resulted in the 2011 Tohoku Earthquake. While cracks of 10 cm to 20 cm could be identified in the road connecting to the National Route 6 (Figure 13a, no key geotechnical damage was brought by the earthquake, so as the situation after the 2021 earthquake (Figure 13).

Figure 11. Cracks in Watari Town

(a)

(b)

(c)

Figure 12. Re-liquefaction in the Arahama Port: (a) Liquefaction in 2022 (Photo credit to Saito K., and provided by Wakamatsu K.), (b) Liquefaction at the same spot as (a) in 2021 and (c) Liquefaction in 2011 (photos b and c are extracted from Wakamatsu, 2021)

(a) Some deformation occurred on the road

(b)

(c)

Figure 13. Embankment of the Taiyo Newtown: after earthquakes of (a) March 16, 2022, (b) February 13, 2021 and (c) March 11, 2011

Sakamoto, Yamamoto Town, Watari District

Following the damage survey of the 2021 Fukushima Earthquake (Inoue et al., 2021), inspection was made around the Disaster Prevention and Communication Center of Yamamoto Town (37°55'20.0"N, 140°53'52.0"E). Cracks and ground settlement could be observed in the surrounding ground of the Center (Figure 14a). On the National Route 6 in Sakamoto of Yamamoto Town (37°55'35.2"N, 140°53'54.4"E), 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 (Figure 14b).

(a) Disaster Prevention and Communication Center of Yamamoto Town

(b) Crack in Route 6 and uplift in a nearby petrol station

Figure 14. Damages in Yamamoto Town

Slope failure in Miyagi

Tarumizu Dam, Natori City (38°10'45.5"N, 140°50'37.2"E)

Massive landslide was inspected along the road leading from the top-left water dam and the dam office (Figure 15). The 4m-wide road was fully blocked by the landslide debris which was made up of the shotcrete, rock, mud, and trees. 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 at this site. The crest of scarp area was about 15 m high from the road level. The width and depth of the landslide were about 10 m and 1 m respectively. The failed section was of the largest slope height compared to the adjacent slope also reinforced by shotcrete. The influence of seismic motion could thus add to the driving force and reduce the factor of safety. Possible failure mechanisms should be investigated in the future.

Figure 15. Landslide at Tarumizu Dam

Damage to infrastructure in Miyagi

Tohoku Expressway in Shiroishi City (37°59'39.6"N, 140°36'27.3"E)

The Tohoku Expressway was affected by moderate ground cracking and settlement associated with the 2022 Fukushima Earthquake (Figure 16). Bumps in the road were frequently encountered. A length of approximately 50 m 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 Figure 17, cracks induced by this 2022 earthquake were identified at localities marked by red dots. Yellow dots indicate locations with cracking which propagated after the ground shaking while blue dots are locations with existing cracks. The new cracks occurred mainly in the vicinity of the boundary between box culvert and embankment regions. They are also concentrated in the western side of Shiroishi City, for instance, near Box Culvert Kunimi 65, 66, 67, 69, 71 and 75.

Figure 16. Road section near Box Culvert Kunimi 71, at 293.73 KP (37°59'39.5"N, 140°36'26.3"E): repaired crack

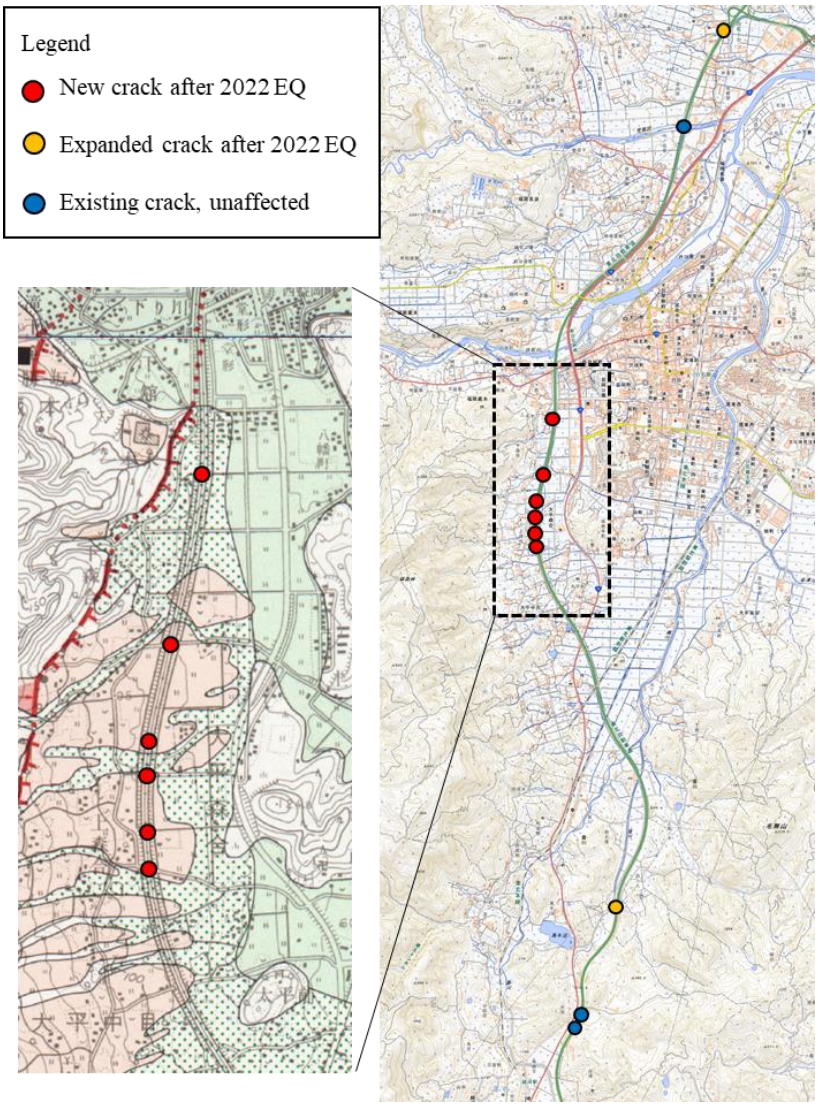


Figure 17. Distribution of ground cracking, created based on map information of the Geospatial Information Authority of Japan (GSI, 2022)

CONCLUSIONS

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.

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REFERENCES

Abukumajiho. (2021, February 15). *鏡石町は３カ所の通行止め続く [Traffic suspension in 3 locations in Kagamiishi Town].* Retrieved from https://abukumajiho.com/news/20210215_10002

Geological Survey of Japan, AIST. (1996). *Quadrangle Series 1:50,000 Soma-Nakamura.* Retrieved from https://www.gsj.jp/data/50KGM/JPG/GSJ_MAP_G050_07025_1996_200dpi.jpg

GSI. (2022, March 25). Retrieved from GSI Maps: https://maps.gsi.go.jp

Inoue, K., Kiyota, T., Shiga, M., Dang, J., & Wang, X. (2021). *Preliminary Report of the Damage by the 2021 Off Fukushima Prefecture Earthquake Mj7.3, Japan.* Japan: JSCE.

Japan Meterological Agency. (2022, March 17). *Earthquake information：Detail information.* Retrieved from https://www.data.jma.go.jp/multi/quake/quake_detail.html?eventID=20220317001109&lang=en

JR East. (2022, March 17). *福島県沖で発生した地震による東北新幹線の被災状況について [Regarding damages to the Tohoku Shinkansen due to the Fukushima Earthquake].* Retrieved from https://www.jreast.co.jp/press/2021/20220317_ho01.pdf

MLIT, Japanese Government. (2022, March 25). *福島県沖を震源とする地震について(第11報) [the 11th report regarding the Off coast of Fukushima Earthquake].* Retrieved from 災害・防災情報 [Disaster and Prevention Information]: https://www.mlit.go.jp/common/001472781.pdf

NIED. (2022, March 22). *福島県沖の地震による強震動*. Retrieved from K-NET. KiK-net: https://www.kyoshin.bosai.go.jp/kyoshin/topics/html20220316233630/main_20220316233630.html

USGS. (2022, March 16). *M 7.3 - 57 km ENE of Namie, Japan*. Retrieved from U.S. Geological Survey - Earthquake Hazards Program: https://earthquake.usgs.gov/earthquakes/eventpage/us6000h519/executive

Wakamatsu, K. (2021, February 25). *2021年2月13日福島県沖の地震による再液状化（宮城県亘理町の事例）[Reliquefaction due to the February 13, 2021 off Fukushima Earthquake (Case history in Watari Town, Miyagi Prefecture].* Retrieved from Japan Association for Earthquake Engineering: https://www.jaee.gr.jp/jp/wp-content/uploads/2021/02/210213liquefaction.pdf