IPA News Letter Volume 7, Issue 4 December 2022

Special Contribution

Steel Pipe Piles, Tubular Sheet Piles, Steel Sheet Piles Confronting Natural Disasters

Toshiharu Hirose

Manager
Japanese Technical Association for Steel Pipe Piles and Sheet Piles (JASPP)

The Japanese archipelago is an arcuate archipelago located off the eastern coast of the Eurasian Continent and in the northwestern coast of the Pacific Ocean, where the oceanic plates of the Pacific and the Philippine Sea plates subduct beneath the continental plates of the Eurasian and the North American plates. For this reason, trench-shaped submarine depressions called ocean trenches and ocean basins (troughs) exist off the south and east coasts of the Japanese archipelago, which frequently generates plate boundary earthquakes in these areas. In addition, cracks (faults) are formed in the land area of the surface of the plate as the continental plate is pushed by the oceanic plate, where intra-continental plate earthquakes, also called fault earthquakes or active fault earthquakes, often occur.

Surrounded by the Sea of Japan, the Sea of Okhotsk, the Pacific Ocean, and the East China Sea, the Japanese archipelago has a mild climate with four distinct seasons. On the other hand, it suffers wind and flood damage quite frequently, as steep mountainous areas account for 70% of the country, and besides, it often has heavy rain caused by mobile low-pressure systems and typhoons. Furthermore, climate change due to global warming in recent years, so-called guerrilla rainfalls (localized heavy rain), and localized heavy rain caused by the occurrence of linear rainfall belts have caused large-scale landslides and floods many times.

1. Steel pipe piles, tubular sheet piles and steel sheet piles in earthquake disasters

(1) 1964 Niigata Earthquake (M7.5): Major damage to a modern city due to liquefaction

At 13:01 on June 16th, 1964, this earthquake occurred with the epicenter about 40km south of Awashima Island in Niigata Prefecture. A large-scale liquefaction phenomenon occurred throughout Niigata City, which caused extensive damage to social infrastructure facilities such as rivers, ports, airports, railways, and general buildings. This earthquake captured worldwide attention as it was the first case where a modern city experienced large-scale liquefaction.

In Niigata City, reinforced concrete buildings suffered the most damage. More than 300 out of 1,500 buildings in the city were damaged, but 189 buildings sank or slanted without any damage to their superstructures. At the "Prefectural Kawagishi-cho Apartments" located on the left bank of the Shinano River, 3 out of 8 buildings were greatly tilted due to the liquefaction phenomenon, and one of them was almost overturned. It was also the time when color television began to spread, and the shocking images made the liquefaction damage known to the general public.

After the earthquake, a large number of investigators were dispatched from related organizations in order to investigate the damage situation to the buildings and in order to consider restoration methods as well. Since there was no fatal damage to the superstructures of the damaged buildings, there were few cases of demolishing and rebuilding even heavily sloping buildings. Most of the buildings were restored by raising the foundations in some way.

The Niigata Telecommunications Department Office Building (Photo 1.1) suffered damage with a maximum subsidence of 530 mm and a maximum tilt of 1/40 to 1/50, but no harmful cracks were found in the structure.

In this case of building restoration, in addition to the following reasons: (1) there was no damage that might hinder its continued use, (2) it was not desired to spend the cost of newly rebuilding it, (3) similar re-damage should be avoided, considering the construction cost and construction period, a method was adopted in which “as a structure to support the building, steel pipe piles were to be pressed into the foundations of the columns to raise the building horizontally”. For the restoration, while using the second floor and above of the building, steel pipe piles with a length of 1.0m were added, and the number of steel pipe piles corresponding to the column load were pressed in with a jack. Concrete was placed on the top of the pile, which was used as a jack fulcrum when raising the building (Fig. 1.1).

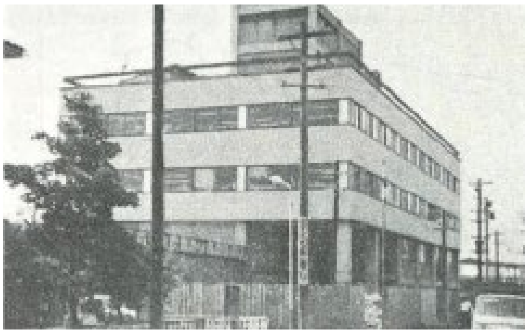

Photo1.1 Niigata Telecommunications Dept. Office Building[1)]

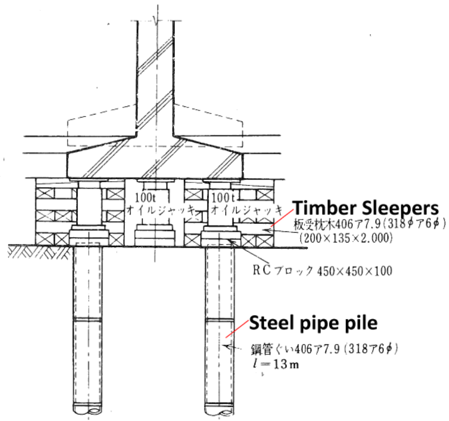

Fig.1.1 Detailed Drawing of Leveling[1)]

(2) 1968 Tokachi-oki Earthquake (M7.9): Standards were revised due to the damage to RC (Reinforced concrete) buildings

At 9:48 on May 16, 1968, the earthquake occurred with the epicenter off the east coast of Aomori Prefecture (far off Sanriku). The damage occurred from Tohoku Region to Hokkaido centering on Aomori Prefecture, with a 3m high tsunami hitting Erimo Cape in Hokkaido and a 3 to 5m high tsunami hitting Sanriku. There were geo-disasters that caused 52 casualties. 673 buildings were completely destroyed, 3,004 were partially destroyed, and 15,697 were partially damaged. Especially in Aomori Prefecture, reinforced concrete public buildings which had been built after 1960, such as Misawa Commercial High School (Photo 1.2), Hachinohe Higashi High School, Hachinohe Technical College, and Mutsu City Hall, were severely damaged. This led to the revision of the "Building Standard Law Enforcement Order", and also the "Standard for Structural Calculation of Reinforced Concrete Structures (Architectural Institute of Japan)" in 1971.

(3)1978 Miyagiken-Oki Earthquake (M7.4): The first earthquake to hit a large city with a population of over 500,000.

At 5:14 p.m. on June 12, 1978, this earthquake occurred with the epicenter (seismic intensity 5) approximately 100 km off the east coast of Sendai City, Miyagi Prefecture. Liquefaction caused damage to the lifelines such as gas and water supply on flat land along the coast, and conspicuous damage was caused to the first floors of buildings in industrial complexes located on reclaimed land. Landslides and collapses occurred at the boundary between the natural ground and embankments in new residential areas built on hilly areas. This turned out to be a heavy damage where 4,385 houses were completely or partially destroyed, and 86,010 houses were partially damaged. It was regarded as a typical urban earthquake that a large city with a population of more than 500,000 people encountered for the first time.

In this earthquake, excavation surveys were actively carried out on the foundation piles of building structures, and it was clarified that (1) PC piles (prestressed concrete piles), especially AC piles (high-strength concrete piles), were significantly damaged, (2) in the case of the buildings which had damaged piles, the ground was not extremely soft, but slightly soft. On the other hand, in the hilly residential area near the center of Sendai city built after 1960, many landslides occurred on the embankment. It was reported, however, that there happened no damage from the Tohoku-Pacific Ocean Earthquake that occurred later in March 2011, in the area where the collapsed land had been turned into a green space and a concrete leaning retaining wall had been constructed with a steel pipe pile foundation that also had served as an earth retaining wall, as a restoration method. (Photo 1.3).

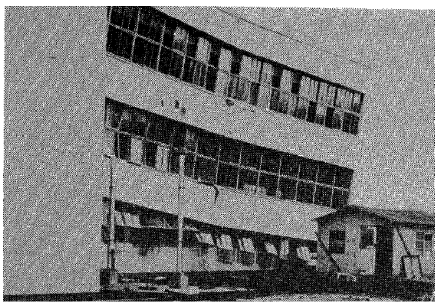

Photo 1.2 Damaged building of Misawa Commercial High School[2)]

Photo 1.3 Affected area in Sendai City[3)]

(4)1995 Hyogo-ken Nanbu Earthquake (M7.3): Steel pipe pile foundation demonstrated excellent seismic performance

At 5:46 on January 17, 1995, the earthquake occurred at the bottom of the Akashi Strait, with the epicenter at a depth of 16 km. It was the first large-scale earthquake with a seismic intensity of 7 recorded in Japan, which caused a major disaster that killed more than 6,000 people, mainly in the city of Kobe. It caused extensive damage to the infrastructure facilities such as roads, railways and ports, buildings such as ordinary houses, offices and condominiums, and the lifelines such as electricity, water and gas. Turning out to be an unprecedented earthquake disaster, it was later called the Great Hanshin-Awaji Earthquake.

Steel foundations and steel structures such as steel pipe piles, tubular sheet piles, and steel sheet piles had been used in many coastal facilities and structures including landfills. These damage conditions had something in common, and most of them were judged to be the effects of lateral displacement due to liquefaction of the surface ground and the backfill soil, sliding failure of the ground due to reduction in effective stress, etc. In addition, there were cases in which steel pipe piles used for piers were damaged because of the deterioration of the bearing strength of the pile material caused by the progress of corrosion due to insufficient anti-corrosion treatment. However, it was confirmed that many steel foundations and steel structures were generally sound, which turned out to show the characteristics of "steel" such as high strength and excellent deformation performance.

1) Damage to steel pipe piles, tubular sheet piles, and steel sheet piles in revetments, quay wall structures, etc.
A visual inspection was carried out by ship from the sea side for the seawalls, quay walls, piers, pier foundations, etc. which had used steel pipe piles, tubular sheet piles, and steel sheet piles in the coastal reclaimed land of Maya Wharf, eastern construction area, Ashiyahama, Nishinomiyahama, and Kobe Port Island, and Rokko Island as the target areas. Tables 1.1 and 1.2 show the damage status of structures and the damage rank of structures. About 70% of the 23 surveyed structures had no damage to the steel pipe piles (damage rank: A, B).

Table 1.1 Damage to structures [4)]

Damge situation / Structures	A	B	C	D	Total
Seawall	2				2
Quay	1			1	2
Jetty quay	6	1	4		11
Pier Foundation	3	1			4
Locks/water gates	2				2
Facility foundation, etc.				2	2
Total	14	2	4	3	23

Table1.2 Damage ranks of structures

Damage rank	Damage situation
A	The superstructure, facilities, and foundation piles are all sound and functionally unaffected.
B	There is damage to the superstructure and facilities (functional impediment), but the foundation piles are sound.
C	There is damage to the superstructure and facilities (functional impediment), and some of the foundation piles need to be repaired and reinforced.
D	Damage to the superstructure, facilities, and foundation piles (functional impediment)

Note: Produced based on the information given in Table 1.1

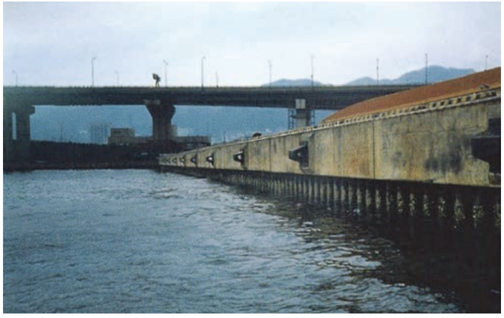

Photo 1.4 West side of Maya Wharf[6)]

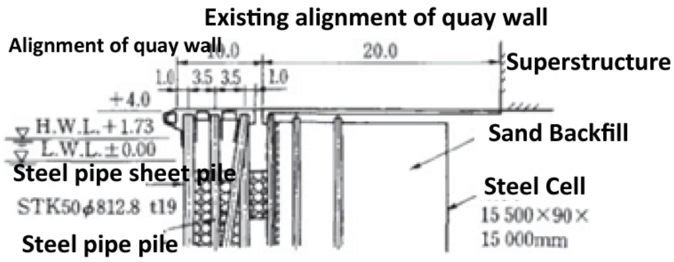

Fig. 1.2 Foundation of the west side of Maya Wharf[7)]

a) Damage to revetments and quay walls

At Port Island and Rokko Island, gravity caisson quays suffered severe damage, while pier structures suffered minor damage. "The Maya Wharf No. 1 Jetty West Quay (Photo 1.4)" was a seismic revetment with a horizontal design seismic intensity of 0.25. In the vicinity of the base of this jetty, a counterweight fill was placed on the sea side of the existing steel plate cell foundation, and further, a double-layer structure was adopted with a new quay-wall of steel pipe sheet piles with battered piles installed (Fig. 1.2). In addition, the tip of the pier had a very solid double-foundation quay with a steel plate cell on the land side and a caisson on the sea side, and although there were some cracks in the concrete due to uneven subsidence at the connection part between the horizontal pier and the caisson, there was no functional problem after the disaster.

On the other hand, the quay on the east side of Maya Wharf was a steel plate cell type quay that partially used OD400 (400mm in outer diameter) and OD500 steel pipe piles in the apron part, but the steel plate cells tilted toward the sea and buckling occurred in the steel pipe pile heads, and the function of the quay was hindered. The cause was attributed to the fact that the excessive horizontal force acted on the piles in the apron as the steel plate cells tilted forward due to the excessive flow pressure and the vertical and horizontal seismic motion because of the liquefaction.

b) Damage to the pier type wharf

Of the 11 surveys of pier type quay walls, 4 were functionally impaired. The characteristics of the damage common to these were as follows.

1, The caisson-type revetment on the land side was displaced toward the sea from the existing revetment line, and the revetment was inclined toward the sea.
2, Pier structures have two types; A structure type composed of vertical piles, and a type of vertical and better piles, and buckling was observed in steel pipe piles.
3, The top of the pier was slanted toward the land (in some quays, toward the sea).

At a certain quay, damage (one case) was observed in which one of the piles was broken in the direction perpendicular to the pile axis. The main cause was attributed to the fact that the thickness of the steel pipe plate was reduced due to corrosion because of insufficient anti-corrosion protection on the aging pier. Whereas no damage was observed in the structures for which new anti-corrosion methods had been adopted such as heavy anti-corrosion coating and FRP cover, and sufficient anti-corrosion measures.

c) Facility foundations (walkway behind the quay, foundations of ancillary facilities such as land-side cranes, etc.) and other damage situations.

At the Higashi-Kobe ferry wharf, the caisson quay was displaced approximately 1-2m toward the sea from the existing line, and the ground between the caisson quay and the footpath foundation collapsed about 2-3m. Steel pipe piles of OD400 were used for the footpath foundation, but the steel pipe piles and the footing were completely separated, leaving the steel pipe piles exposed. The main cause was attributed to the fact that the pile head was only embedded about 100 mm into the footing (no pile head rebar).

d) Actual cases of recovery

Shinko Pier No. 4 (-12m quay) (Photo 1.5), located at the base of the Shin-Kobe Ohashi Bridge leading to Port Island, had been used as an international passenger berth. Regarding the restoration method, as there were constraints because it was in the water area in front of the slip (between jetties), and the shed was close behind, a method was adopted in which steel pipe sheet piles were to be placed in front of the existing caissons, and underwater concrete was to be filled between them.

Photo 1.5 Shinko No.4 Pier (-12m quay) [8)]

2) Damage to steel pipe piles in building structures

A visual inspection was conducted on 45 building structures using steel pipe piles in Kobe Port Island, Rokko Island, Fukaehama-cho, and Naruohama-cho. Table 1.3 shows the damage to the foundations of building structures.

Table 1.3 Damage to the foundation of building structures [5)]

	Location conditions	Foundation damage		Sub-total	Total
		No	Yes		
Port Island	Inland	16	0	16	24
	Coastal area	0	8	8	
Rokko Island	Inland	16	40	16	18
	Coastal area	2	0	2	
Fukaehama-cho Naruohama-cho	Inland	2	1	3	3
Total		36	9	45	45

Classification of damage degree
Foundations were damaged: For those with exposed pile heads, the pile heads were damaged such as buckling or deformation, or the footings were damaged or displaced. If the pile heads were not exposed, the footings were obviously damaged or displaced.
No foundation damage: No damage or displacement on piles or footings.

a) Cause of foundation damage

There was no damage to the foundation in 36 out of 45 investigations (80%). Of the 9 cases where damage was confirmed, 8 cases were warehouses adjacent to the container berth in Port Island, and it was presumed that the foundation frame had been displaced due to the lateral displacement of the ground accompanying the berth damage. The other was a building located inland, where the top of the pile was exposed and a slight tilt was observed, but no damage to the superstructure was confirmed. Of the 36 foundations without damage, 4 had exposed steel pipe piles, but no damage such as buckling or deformation was observed. It was concluded that the reason why the two structures (both warehouses) in the Rokko Island coastal area had no damage to the foundations was that they were located relatively inland and had little impact from the damage to the berth.

b) Damage to the superstructure

Of the 45 cases surveyed, 13 cases had damage to the main body (beams, columns, walls), and there were 11 cases where the main body was sound but incidental facilities (stairs, connecting corridors, elevators, etc.) were damaged. There were 21 cases where both the main body and incidental facilities were sound and the damage was limited to subsidence of the surrounding ground (damage to underground pipes, damage to parking lots and sidewalks).

Of the 13 cases where the main body was damaged, 5 were condominiums and housing complexes, and the other 8 were warehouses adjacent to the container berth. The damage to the condominiums and housing complexes located in the inland area was mainly X-shaped cracks generated on the walls. The damage to the warehouse adjacent to the berth was caused by the movement of the foundation frame due to lateral displacement of the ground, and tilting and deformation of the entire building.

3) Survey results of the damage to steel pipe piles, tubular sheet piles, and steel sheet piles (summary)

A visual inspection after the Hyogo-ken Nanbu Earthquake (Great Hanshin-Awaji Earthquake) revealed that, except for some cases, most of the independent steel pipe pile foundations such as pier type quays and building foundations were found to be sound, regardless of subsidence of the surrounding ground or damage to the superstructure.

The common point of the revetments, quay structures, and building structures with foundation deformation was that they were all located near the reclaimed revetments. Although there was no direct pile body damage due to the seismic motion, it was speculated that, in the coastal area, the caisson quay walls and revetments moved significantly due to the fluid pressure accompanying the lateral displacement of the ground, which caused deformation and tilting of the steel pipe piles of the pier and the foundations of the factory warehouses located nearby.

(5) 2004 Niigata Prefecture Chuetsu Earthquake (M6.8): Recorded seismic intensity 7 for the second time in recorded history

At 17:56 on October 23, 2004, it occurred with the epicenter 13 km deep in Kawaguchi-cho, Kitauonuma-gun, Niigata Prefecture (currently Nagaoka City). It was an inland earthquake with a maximum seismic intensity of 7, which was the second time in recorded history after the Hyogo-ken Nanbu Earthquake. There were 19 aftershocks with a seismic intensity of 5 lower or more by the end of December of this year.

Due to the rainfall caused by the typhoon that had passed three days before the earthquake, landslides occurred one after another on the slopes of the hills. In the former Yamakoshi Village, houses collapsed with earth and sand (Photo 1.6), and there was damage caused by the outflow of irrigation water from Nishikigoi farming ponds making use of terraced rice fields. In mountainous tributaries, collapsed sediment clogged river channels, forming natural dams that cut off traffic routes, leaving many communities isolated.

Photo 1.6 Landslide at Former Yamakoshi Village[9)]

There is a case of restoration of a railroad bridge damaged by this earthquake by pressing-in a steel sheet pile continuous wall around the damaged pier and thereby carrying out the repair and the seismic reinforcement at the same time. By filling the interior of the steel sheet pile continuous wall with concrete and integrating it with the existing pier, the shear strength and deformation performance of the piers were improved. By installing steel sheet piles (also used as a temporary cofferdam) with a compact press-in machine, the need for large-scale temporary construction work was eliminated and thus the construction period was shortened.

(6) 2011 off the Pacific Coast of Tohoku Earthquake (M9.0): An unprecedented catastrophe caused by a giant tsunami

At 14:46 on March 11, 2011, it occurred with the epicenter off Sanriku, about 70 km east of Sendai City. The huge earthquake that occurred at the boundary between the North American plate and the Pacific plate recorded a magnitude of 9, the largest in Japan's history, and a violent shaking with a maximum seismic intensity of 7 lasted for more than 2 minutes. About 30 minutes after the earthquake, a gigantic tsunami with a wave height of 10 m or more and a maximum run-up height of 40 m swept the Pacific coast of the Tohoku region, causing devastating damage to the coastal areas of Hokkaido, Tohoku and Kanto (Photo 1.7, Photo 1.8). As of March 2021, 15,899 people died and 2,526 people were missing due to this earthquake, 90% of whom were victims of the huge tsunami. It was called the Great East Japan Earthquake because it was an unprecedented earthquake disaster that spread from Hokkaido to Kanto.

Photo 1.7 A huge tsunami that hit Miyako city, Iwate Pref [10)]

Photo 1.8 Seawall damage at Sanriku Town, Ofunato city [10)]

Liquefaction damage was also serious in landfills in the coastal areas and on the soft ground along the rivers. In Urayasu City, Chiba Prefecture, for instance, a large amount of groundwater containing sand erupted, causing manholes to rise and buildings to tilt. The lifelines were also severely damaged. Furthermore, at the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Plant, the electrical system of the reactor was damaged by flooding caused by the huge tsunami, and the core cooling system stopped. As a result, the cooling water inside the reactor pressure vessel evaporated, and as the water level dropped, the hydrogen generated by the chemical reaction between the exposed fuel rods and the steam leaked into the reactor building and exploded, causing the ceiling and walls to be destroyed. After all, evacuation of residents still continues in some areas because of the scattering of highly concentrated radioactive materials caused by the venting that was carried out to lower the pressure inside the reactor containment vessel. It was an accident that raised a big problem to society regarding the safety of nuclear power plants.

After the earthquake, our association conducted surveys on steel foundations and steel structures such as steel pipe piles, tubular sheet piles, and steel sheet piles in various fields such as roads, railways, ports, and construction. The result was published as a report (October 2011)[11] and a second report (December 2012)[12].

Photo 1.9 Bearing deformation[11]

Photo 1.10 Damage to Kamaishi Bay mouth breakwater[10]

1) Damage to structures using steel pipe piles, tubular sheet piles, and steel sheet piles

The damage to structures using steel pipe piles, tubular sheet piles, and steel sheet piles in the Great East Japan Earthquake was as follows.

a) Road and railway field

No major deformation was found in the main bodies of the bridge foundations, except for the bridges whose superstructure and substructure were washed away by the tsunami. As for the bridges that were washed away, it was assumed that the damage to the foundations themselves due to the seismic motion was minor. As damage to the foundation bodies due to the earthquake motion, although some deformation of the bearings and cracks on the embankment slopes at the abutments were confirmed, no major deformation was confirmed in the foundation bodies, and they were found almost sound (Photo 1.9).

b) Construction field

In many areas, the tsunami caused enormous damage such as the outflow, overturning, collapse, and inclination of buildings. In Onagawa Town, the tsunami also caused pile foundation structures to fall over (Table 1.4). On the other hand, no damage was confirmed in the structural frame of the building using the steel pipe pile foundation.

c) Port field

The post-earthquake tsunami caused major damage to breakwaters and seawalls in many areas of the Tohoku region, including collapse, etc. (Photo 1.10), but damage to quay walls and seawalls was limited.

Table 1.4 Damage to overturned buildings(pile foundation structures) in Onagawa Town[12)]

Damaged buildings	Onagawa Police Box	Ejima Kyosai Hall	Hotel building	Seafood processing warehouse
Structure scale	2 story RC building Long side x short side x height = 10m x 4.8m x 10m Tower ratio: short side = 2.08 long side = 1.00	3 story steel building (partially 4F) Long side x short side x height = 16m x 8.4m x 12m Tower ratio: short side = 1.43 long side = 0.75	RC 4F Long side x short side x height = 5.6m x 5.6m x 14.5m Tower ratio: short side = 2.59 long side = 2.59	RC 2F Long side x short side x height = 20m x 8.8m x 10m Tower ratio: short side = 1.14 long side = 0.50
Damage situation	・Tumble north on the spot ・It seems that PHC piles of OD300 were used for the foundation piles. ・All piles broke near the pile head ・The extracted part is exposed while being connected to the footing ・There are collision marks on the roof and walls	・It seems that the tsunami was received from the short side of the building. ・From the tsunami footage taken in the vicinity, it seems that the building did not topple over until the first wave (pushing wave) of the large tsunami reached the third floor of the building. ・It seems that PHC piles of OD250 were used for the foundation piles. ・At the bottom of the exposed footing, the pile head joint rebar filling concrete, and one pile that was pulled out remain. ・The length of the pulled pile was 6.0m (broken at the originally welded spot?) ・Except for this one stake, the stakes appear to have been left at their original positions on the building.	・It seems that it was swept west (uprush direction) more than 70m from its original position. ・It seems that PHC piles of OD300 were used for the foundation piles. ・Most of the piles broke at the original position of the building. ・Only one pile was dragged as far as the position where the building was washed away and broke. ・At the original position, four piles remained about 2m pulled out.	・It looks like it fell over after being hit by a tsunami (push wave) in the direction of the short side. ・Although there were some traces of having been connected with stakes on the bottom of the footing, (1) No traces of rebar cages, etc., can be confirmed at the joints of the foundation piles. (2) There are no traces of foundation piles embedded in footings. (3) Footing thickness is very small. Therefore, it seems that the footing and the pile were not connected.
Damage photos		 Reprinted from Note 1*	 Reprinted from Note 1*	 Reprinted from Note 2**

Note 1* Yahoo! JAPAN: Great East Japan Earthquake Photo Preservation Project
Note 2** TETSU (Satoshi Nakayama): Tama Watch, May 6, 2011, Tsunami Damage, Onagawa Town, Miyagi Prefecture

2) Steel foundations and steel structures that contributed to restoration and reconstruction

For the recovery and reconstruction of the Tohoku Region Pacific Ocean Earthquake (Great East Japan Earthquake), steel pipe piles, tubular sheet piles, and steel sheet piles were used in a lot of cases because they had excellent strength, deformation performance, quality, and workability for disaster-resistant city development and infrastructure reconstruction. Here introduced are some application cases of steel pipe piles, tubular sheet piles, and steel sheet piles which made a particularly large contribution.

a) Application case of steel pipe piles and steel sheet piles [Ishinomaki disaster recovery work: construction period from October 2011 to March 2014]

[Damage situation]
Due to crustal movement and liquefaction caused by the earthquake, the entire fishing port area settled by approximately 1.3m (average value), and various facilities such as piers and wharves were destroyed or damaged by flooding. The designed water deep -7m quay (extension 270m) and -6m quay (extension 700m) settled about 1.15m in the entire area, and the head of the steel sheet pile in front of the revetment was pushed out to the sea side with a maximum of 46 cm in and out of the sheet pile normal line. Also, the apron collapsed and was constantly submerged.

[Recovery method]
While restoring the original shape, a design was made for the purpose of raising the height of the subsidence, and regarding the steel sheet piles that caused the normal deviation, new sheet piles were installed slightly forward the existing sheet piles (Photo 1.11). A new steel pipe pile was also installed for the H-shaped steel that had collapsed in the existing apron. A steel sheet pile was driven at 1.7m forward the normal line to the old revetment, Steel piles with 600 mm in diameter and 12 to 17 m in length were driven into the apron area, and the front steel sheet piles were tied with about 13m long tie rods to serve as an anchor (Fig. 1.3).

Photo 1.11 New Installation of steel sheet piles of designed water depth - 7m quay[13)]

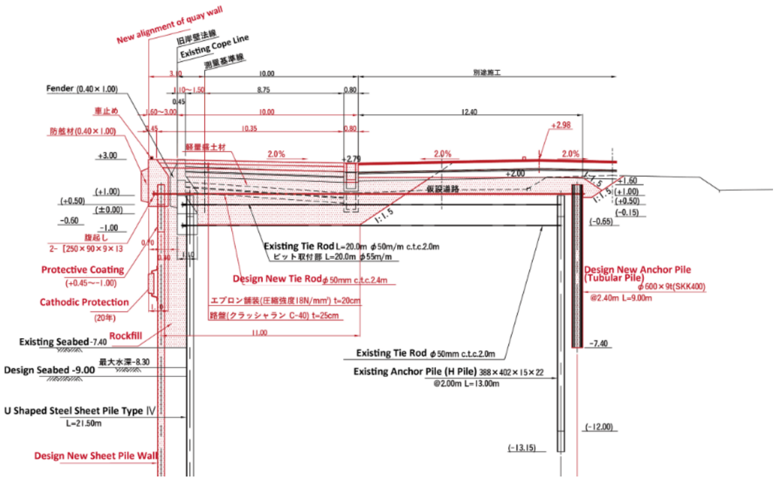

Fig. 1.3 Designed water depth - 7m quay wall restoration standard cross section[13)]

b) Application case of tubular sheet piles [Ishinomaki Port Higashihama Coast Seawall Restoration Work]

[Damage situation]
An upright concrete embankment with TP (Tokyo peil) + 3.3 to 3.5m, which was built in the 1960s and 1970s, settled by approximately 1m due to the earthquake, and besides, the front of the seawall was scoured by the tsunami surge and collapsed during the undertow, resulting in two levee breaches.

[Recovery method]
A new seawall was decided to be constructed as a disaster recovery project, and a plan of an upright embankment with an embankment structure of continuous self-supporting tubular sheet piles with a height of TP + 7.2m was adopted (Fig. 1.4). A normal coastal embankment required a slope on the sea side in order to ensure the specified strength without affecting the harbor road behind it, so a relatively expensive construction cost and a long construction period were issues. For this reason, a continuous wall made of self-supporting tubular sheet piles was adopted as an upright embankment on the sea side which also would be able to suppress lateral flow during liquefaction (Photo 1.12).

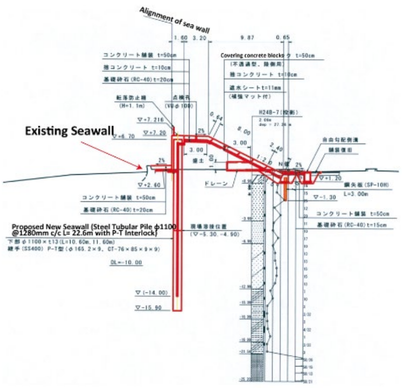

Fig. 1.4 Ishinomaki Port Higashihama coastal seawall standard cross section[14)]

Photo 1.12 Installation of tubular sheet piles on the Higashihama coastal embankment of Ishinomaki Port[14)]

2. Steel pipe piles, tubular sheet piles, and steel sheet piles in the case of typhoon and heavy rain disasters

(1) September 2015 heavy rains in the Kanto and Tohoku regions: Steel sheet piles contributed to the restoration of levee breaches in the first-class rivers

Typhoon No. 18, which occurred on September 7, 2015, went north over the southern Sea of Japan. After making landfall on the Chita Peninsula of Aichi Prefecture at around 10:00 on September 9, it advanced to the Sea of Japan and became an extratropical cyclone at 21:00 on the same day. After that, due to the influence of the moist air of Typhoon No. 17 flowing from the south into the low pressure that had changed from the typhoon, heavy rains spread over a wide area from western Japan to northern Japan, and the Kanto and Tohoku regions experienced record rainfall. In particular, from September 9th to 10th, Nikko City, Tochigi Prefecture, recorded 551 mm of rainfall in 24 hours, which was the highest since observation began in 1975, and other observation points (16 points) also broke observation records for the 24-hour precipitation. Under these circumstances, heavy rain special warnings were issued by the morning of the 10th in Tochigi and Ibaraki prefectures. The Kinugawa River overtopped and overflowed in Ibaraki Prefecture, which is located in the midstream region. In the early afternoon, the embankment on the left bank of the Kinugawa River in Misaka-cho, Joso City, collapsed for approximately 200m. Eventually, a wide area in Joso City sandwiched between the Kinugawa River and the Kokaigawa River was submerged, the city hall main building, which had been completed the previous year, was flooded, and more than 5,000 houses were completely or partially destroyed, causing extensive damage due to long-term flooding (Photo 2.1). The levee breach of the Kinugawa River was the first case since it had occurred in Tochigi Prefecture in August 1949, and the levee breach of a state-managed river in the Kanto region was the first since it had occurred in the Kokaigawa River in August 1986.

The restoration work for the collapsed levee was carried out for two weeks as an emergency restoration by means of a rough cofferdam and steel sheet pile double cofferdam (Fig. 2.1). After that, in January 2016, during the non-flood season, the main restoration work was started. After removing the rough cofferdam and the steel sheet pile double cofferdam that had been constructed during the emergency restoration work, the embankment foundation was replaced, impermeable steel sheet piles were installed to prevent water leakage thorough embankment, and the embankment and bank protection work was carried out and completed at the end of May.

Photo 2.1 Flooding situation in Joso City, Ibaraki Prefecture (9/10)[15)] (Provided by Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism)

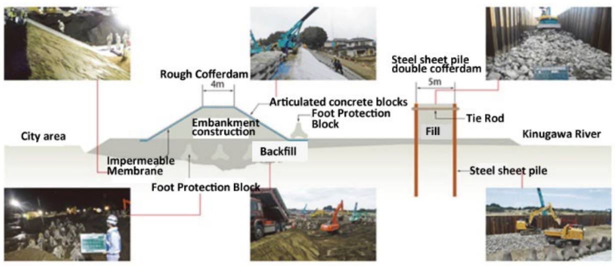

Fig. 2.1 Rough cofferdam, steel sheet pile double cofferdam/standard sectional view [16)] (Provided by Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism)

(2) Heavy rain in July 2018 (Western Japan Heavy Rain): The backwater phenomenon caused severe damage, the worst flood in the Heisei period (1984-2019).

The seasonal rain front, which had been stationary in northern Japan since June 28, moved north toward Hokkaido on July 4, then moved south to western Japan on July 5, and remained stationary near western Japan until July 8. Typhoon No. 7, which had occurred in the south of Japan on June 29th, moved north over the East China Sea, passed out into the Sea of Japan, and turned into an extratropical cyclone at 3:00 pm on July 4th. After that, the warm and extremely humid air continued to be supplied to the vicinity of Japan, and the record heavy rain fell over a wide area from western Japan to the Tokai region.

In Ehime, Okayama, Hiroshima and other prefectures, river floods and geo-disasters occurred one after another, leaving 245 people dead or missing in 14 prefectures. The number of victims of floods and geo-disasters surpassed the cases of heavy rain and typhoon No. 10 in July 1982, turning out to be the worst disaster in the Heisei period. 6,767 houses were completely destroyed and 7,173 houses were flooded above the floor level. There were breaches of the river embankments at 2 spots of the nationally managed rivers and 25 spots of the municipally managed rivers, and 2,581 geo-disasters occurred in 32 prefectures[16)].

In Mabi-cho, Kurashiki City, Okayama Prefecture, low-lying land spreads at the confluence of the Oda River and the Takahashi River, and there often occurs flood damage due to the backwater phenomenon. Although it was an area with high flood risk, urbanization was progressing rapidly with the development of railways and roads. In the Oda River, which was affected by the Takahashi River whose water level rose because of the heavy rain, the backwater phenomenon caused the embankment to burst for about 100m at the confluence region with the Takama River. In addition, there occurred embankment collapses at 8 spots, and the water overflowed at 4 spots, flooding an area of 1,200 ha and flooding 4,600 houses (Photo 2.2). The turbid current that flowed into the floodplain surrounded by the embankments of the Takahashi River and the Oda River had no place to escape in the closed area, and the maximum inundation depth reached 5m. Many residents were unable to escape, and 51 people died.

The Oda River's emergency countermeasure work consisted of rough coffering of the embankment where it had collapsed using sandbags and sheets. After that, a steel sheet pile double cofferdam was constructed behind the rough cofferdam in order to construct a temporary embankment for temporary use. The construction of the steel sheet piles was carried out around the clock (Photo 2.3), and the emergency work was completed in a total of 14 days (Photo 2.4).

Photo 2.2 Collapsed Odagawa embankment[18)]

Photo 2.3 Double cofferdam of steel sheet piles driven 24 hours a day[18)]

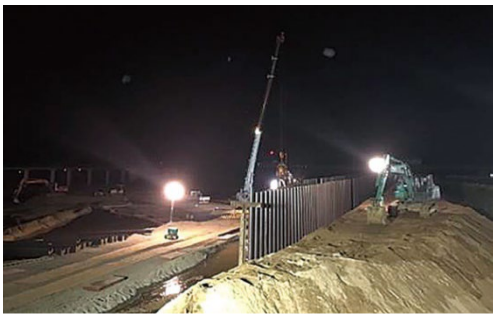

Photo 2.4 Completion status of steel sheet pile double cofferdam[18)]

3. For future disaster prevention and mitigation (the roles required of steel pipe piles, tubular sheet piles, and steel sheet piles)

(1) Social contribution to the realization of national resilience
Based on the lessons learned from the Great East Japan Earthquake, as a basic law to promote nation-building that shall protect the lives and properties of the people from large-scale disasters and accidents, the "Basic Law for National Resilience (2013 Law No. 95)" was enacted and enforced by lawmakers in 2013, and based on it, the Cabinet approved the Basic Plan for National Resilience in June 2014. In this plan, as a basic concept, we will go beyond the scope of "disaster prevention" in the conventional narrow sense, and no matter what kind of disaster occurs,

1, The protection of human life shall be maximized.
2, Important functions of the state and society shall be maintained without being fatally damaged.
3, Damage to public property and public facilities shall be minimized.
4, Rapid recovery and reconstruction

with the above four items as the basic goals, it is proclaimed to promote "national resilience" to build a safe and secure national land, region, and economic society with "strength" and "resilience." In addition, it states that the public and private sectors will vigorously pursue initiatives and comprehensively promote them across ministries and agencies in cooperation with local governments.

Steel pipe piles, tubular sheet piles, and steel sheet piles, which have contributed to the construction of various new infrastructures, are expected to contribute greatly to the realization of national resilience, taking advantage of their excellent properties (strength, deformation performance, quality, workability, workability, etc.) to protect the country from natural disasters as a clue to reduce disaster.

(2) International contributions to the realization of a better and more sustainable world
As in Japan, natural disasters occur frequently in all regions of the world, such as sea level rise due to global warming, torrential rains and storms caused by growing tropical cyclones, accompanying wind and flood damage and geo-disasters, as well as earthquake damage, geo-disasters , tsunamis caused by earthquakes and volcanic eruptions, etc. In order to realize a "sustainable and better world" in the future, it is essential to develop and rebuild infrastructure in every country in the world. Confronting many natural disasters, while being overwhelmed countless times, Japan has advanced and developed its goods and technologies. Japan should make use of its strengths and keep striving to contribute to the resolution of international issues in cooperation with other countries and international organizations.

Fortunately, steel pipe piles, tubular sheet piles, and steel sheet piles are ready-made products, and in extreme terms, they can be transported anywhere in the world. In particular, since the press-in method makes it possible to construct tubular sheet piles and steel sheet piles with relatively small construction machines, it is an ideal method for emergency measures and restoration work in the event of a natural disaster. While combining the convenience and performance of steel materials with the excellent workability of the press-in method, we would be more than happy if we could make an international contribution by aiming to spread this method all over the world

4. Conclusion

In this article, due to space limitations, we selected and introduced domestic disasters that have become important occasions which turned out to demonstrate the significance of steel pipe piles, tubular sheet piles, and steel sheet piles. It was discussed how steel pipe piles, tubular sheet piles, and steel sheet piles have contributed to disaster prevention, mitigation, and disaster recovery. In addition, in the cases where unfortunately damage occurred but they failed to contribute to disaster prevention or mitigation, the causes were explained.

In Japan, where natural disasters occur frequently, steel pipe piles, tubular sheet piles, and steel sheet piles have been playing an important role for infrastructure development and urban formation. With the exception of some cases, no fatal damage has been confirmed even in the massive earthquakes and giant tsunamis rarely seen in human history, such as the Hyogo-ken Nanbu Earthquake (Great Hanshin-Awaji Earthquake) and the Tohoku-Pacific Ocean Earthquake (Great East Japan Earthquake). In addition, it has been recognized again that it is a useful material that can greatly contribute to early recovery after a disaster. This is synonymous with the fact that the characteristics of the material were fully demonstrated because the construction had been appropriately conducted, which means that the importance of construction was reacknowledged at the same time.

In the future, whereas there is an urgent need to respond to new issues such as the promotion of aging and earthquake resistance measures as well as the development of disaster prevention bases, we are determined to continue to work with steel pipe piles, tubular sheet piles, and steel sheet piles that would contribute to society while coordinating with the construction, aiming for a safe and secure society.

REFERENCES

1) Keiki Mase(1978): Restoration works of buildings in Niigata Earthquake, Kiso-ko (The Foundation Engineering & Equipment, Monthly), Vol.6 No.11, pp.94-103. (in Japanese)
2) National Research Institute for Earth Science and Disaster Resilience(1969): 1968 Tokachi Oki Earthquake Disaster Report, National Research Institute for Earth Science and Disaster Resilience Research Report, p.46.(in Japanese)
3) Google Maps, https://www.google.co.jp/maps/@38.2311839,140.865029,19.25z, (accessed on August 27, 2022)
4) Kozai Club and Japan Association for Steel Pipe Piles (1995): Great Hanshin Earthquake Disaster Report on Steel Pipe Piles Foundation (primary) revised version, p.6. (in Japanese)
5) Kozai Club and Japan Association for Steel Pipe Piles (1995): Great Hanshin Earthquake Disaster Report on Steel Pipe Piles Foundation (primary) revised version, p.25. (in Japanese)
6) Kozai Club and Japan Association for Steel Pipe Piles (1995): Great Hanshin Earthquake Disaster Report on Steel Pipe Piles Foundation (primary) revised version, p.13. (in Japanese)
7) Shimizu Institute of Technology (1995): 1995 Great Hanshin Earthquake Disaster Report, p.117, (in Japanese).
8) Kobe Port Office, Kinki Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism: Footprint of recovery from Hyogo-ken Nanbu Earthquake/ Disaster prevention of Port/ To know Port, http://www.pa.kkr.mlit.go.jp/kobeport/pdf/know/shinsai_sokuseki.pdf, (accessed on September 16, 2022) (in Japanese)
9) Ministry of Land, Infrastructure, Transport and Tourism Water Disaster Management Bureau (2005): Disaster Archipelago 2005, p.39, https://www.mlit.go.jp/river/pamphlet_jirei/bousai/saigai/2005/, (accessed on September 16, 2022) (in Japanese)
10) Preservation Project of Photographs at 2011 Great East Japan Earthquake, Yahoo ! JAPAN, https://archive-shinsai.yahoo.co.jp/, (accessed on September 7, 2022)
11) Japan Technical Association for Steel Pipe piles and Steel Sheet Piles (2011): Great East Japan Earthquake Primary Disaster Report, p.6, (in Japanese)
12) Japan Technical Association for Steel Pipe piles and Steel Sheet Piles(2012): Great East Japan Earthquake Secondary Disaster Report, p.16, (in Japanese)
13) Japan Technical Association for Steel Pipe piles and Steel Sheet Piles(2013): Constructing tomorrow, Vol. 81, p.5, (in Japanese)
14) Japan Technical Association for Steel Pipe piles and Steel Sheet Piles(2015): Constructing tomorrow, Vol.83, p.9, (in Japanese)
15) Ministry of Land, Infrastructure, Transport and Tourism, Kanto Regional Development Bureau(2015): Information on September 2015 Heavy Rain in Kanto/Tohoku Region, https://www.ktr.mlit.go.jp/bousai/bousai00000167.html, (accessed on September 16, 2022), https://www.ktr.mlit.go.jp/bousai/bousai00000171.html, (accessed on September 16, 2022) (in Japanese)
16) Japan Technical Association for Steel Pipe piles and Steel Sheet Piles(2021): Looking backward to the past half century and looking forward to the next half century, Commemorative Issue of 50th Anniversary of Japan Technical Association for Steel Pipe piles and Steel Sheet Piles, p.129. http://www.jaspp.com/topics/50th_anniversary_magazine.html, (accessed on September 16, 2022) (in Japanese)
17) Cabinet Office (2018): Situation of July 2018 Heavy Rain Disaster, Disaster Prevention Information, https://www.bousai.go.jp/kinkyu_index.html, (accessed on September 16, 2022) (in Japanese)
18) Ministry of Land, Infrastructure, Transport and Tourism, Chugoku Regional Development Bureau (2019): Record of July 2018 Heavy Rain~Disaster Response by Chugoku Regional Development Burea~, 385p. http://www.cgr.mlit.go.jp/photo/h3007gouu_kiroku/index.htm, (accessed on September 16, 2022) (in Japanese)

◆ A brief CV of Mr. Toshiharu Hirose

After graduating from Shibaura Institute of Technology in 1987, Hirose joined Kubota Corporation where he was involved in developing demand for steel pipe piles in the construction market, technical studies on design and construction, and development of construction methods, etc. In June 1989, he joined the activities of the JASPP. He has served as the chairman of the Technical Committee from 2004 to 2021. Currently, He is involved in the management of the JASPP as the Technical Director of the JASPP.