Protection of a tsunami refuge building with pressed-in sheet pile flood walls

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ABSTRACT

1.6 m high steel sheet pile walls with concrete cover were built on the perimeter of a high school campus to isolate the school buildings from future flooding in the regional city of Naruto in southwestern Japan. This was part of the local government's model project to provide a tsunami refuge facility in the area where no other practical alternatives exist for the students or nearby residents. The project entailed renovation of an existing school building into a new four-story dual-purpose facility with an external staircase from the ground to the flat roof where toilets and storage facilities for emergency needs were added. This would allow students, school staff, and local residents to escape to safety when tsunamis or tidal surges threaten the area. 7 to 10 m long sheet piles were installed through a liquefiable sand layer to avoid the walls' failure during earthquakes and seepage from outside flood water. The press-in piling method was utilized so as not to disturb students or nearby residents with noise or vibration that would accompany conventional pile driving.

Key words: *Press-in piling, Sheet pile, Liquefaction, Tsunami refuge building*

1. Background

1.1. Emergency refuge facilities for seismic and tsunami events

After major natural disasters, school buildings are often used as emergency refuge facilities worldwide. In the case of the 2011 Great East Japan Earthquake and Tsunami, many schools in the affected areas were used as refuge bases for evacuees even long after the original use for education resumed. This was necessitated by the unprecedented scale of destruction and time-consuming recovery. Based on that experience and those from previous disasters, the Ministry of Education and Science of the Japanese government published a report in 2020 titled "Case Studies on Disaster Preventive Functions of School Facilities to be Used as Refuge (in Japanese)" as a reference for the country's school districts. The report emphasizes the importance of the following elements of the school building refuge facilities.

- Safety and resiliency of the facilities involved.
- Fulfillment of the functions as emergency refuge.
- Pre-planning of the facilities' operational management.
- Expedient resumption of use as schools.

1.2 Case Study Project Location

One of the case studies covered in the report was a high school in the city of Naruto with approximately 650 students and 70 teachers/staffers. The city is in an active seismic zone and its population centers are on a low-lying riverine delta at the mouth of the Yoshino River. According to written records of the last 400 years or so, the area has been experiencing a major earthquake every one hundred to one hundred and fifty years. The Nankai Trough, a major offshore fault, is believed to be the cause of these earthquakes. See **Fig. 1** for the locations of the project and the Nankai Trough and **Fig. 2** for the project's plan view with the locations of the perimeter walls and the school buildings on campus.

Fig. 1 Project Location and Nankai Trough

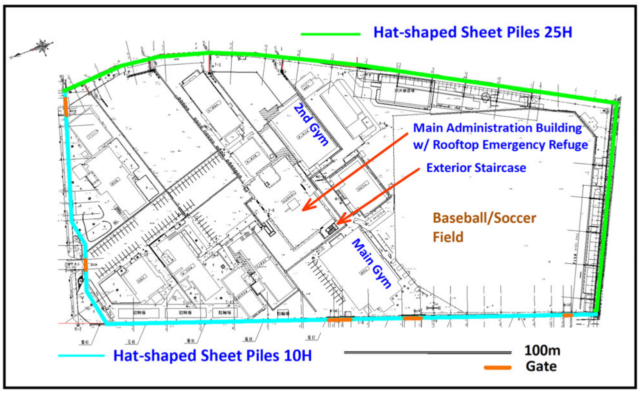

Fig. 2 Plan view of the campus showing the locations of flood walls and buildings

1.3 Objectives of the project

The Tokushima prefectural government, who is responsible for the area's public education, decided to upgrade some of the high school buildings to make the schools as the tsunami and flood emergency refuge centers for this part of the city because there were no high-rise buildings or any high ground nearby to escape to. The elevation of the high school campus is merely 1 meter above sea level and the one long side of the campus is edged with a waterway and wetlands. The following improvement was made to achieve the planned goal.

- 1.6-meter-high flood walls were constructed on the entire perimeter (889 meters including 5 gates) of the school campus to isolate the school from flooding.
- An existing low-rise main administration building was converted to have 4 stories with the a 7,000-liter water tank, a 72kwh generator, 26kw solar panels, and emergency supplies in storage placed on the roof plus an exterior staircase directly connected to the roof.
- The second gymnasium was renovated to have higher seismic resiliency to be used as a refuge facility in case of need.

1.4 Selection of Flood Wall Height

According to Naruto city's online Tsunami Refuge Maps, the reference tsunami water levels at the school location and the surrounding area are between 2.0 to 4.0 meters above the ground. Although the authors were not able to gain access to the planning details of the design requirements, the 1.6-meter height of the perimeter flood walls appears to have been determined to meet lower flooding levels which occur more often than the full reference tsunami height. The refuge functions created at higher elevations in the renovated buildings are clearly above the tsunami reference height.

1.5 Ground conditions and liquefaction potential

The project's ground is very soft, predominantly with sandy silt and silty sand with the STP *N* values between 2 and 17 through the depth of 9m as shown in **Fig. 3**.

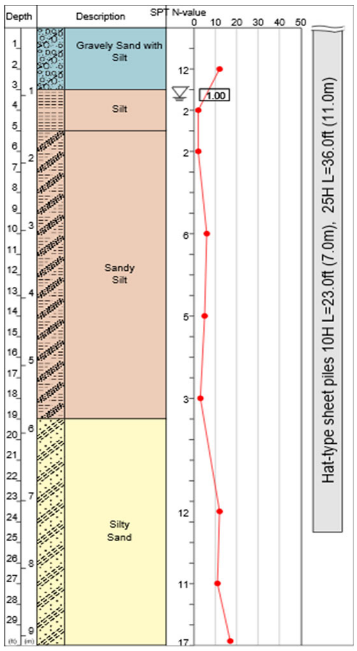

Fig. 3 Bore hole log with required sheet pile

Liquefaction has been observed in this river delta area during strong earthquakes in the past. It is believed that the cause of liquefaction was the soft granular soil with high groundwater level.

2. Structural type and sheet pile installation

2.1. Sheet pile type used

To achieve the goals described in **Section 1.3**, 11.0-meter long 25H Type Hat-shaped sheet piles were selected for the perimeter that faced a canal and wetlands, while 10H Type Hat-shaped steel sheet piles in length of 7.0 meters were selected for the foundation of the other perimeter walls. **Fig. 4** shows the sections and dimensions of these 900mm wide sheet piles while **Table 1** shows their physical properties. These Hat-shaped sheet piles became commercially available in 2005 and have been widely used for permanent structures. Per unit section modulus and moment of inertia of Hat-shaped sheets are superior to those of U-sheets (Harata et al. 2008), which are used more often for temporary structures in Japan due to their higher durability for repeated usage.

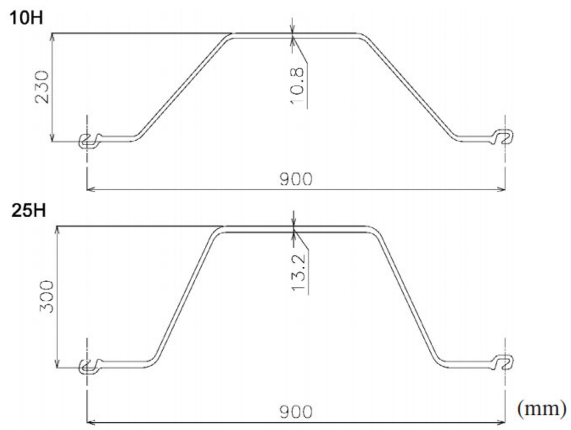

Fig. 4 Hat-shaped 10H and 25H sheet pile sections used for the project (Harata et al.2008)

Table 1 Physical properties of Hat-shaped sheet piles (Harata et al. 2008)

Type	Dimension			Properties per meter of wall			
	Effective width	Effective height	Thickness	Sectional area	Moment of inertia	Section modulus	Unit mass
	mm	mm	mm	cm^2	cm^4	cm^3	kg/m
10H	900	230	10.8	122.2	10,500	902	96.0
25H	900	300	13.2	160.4	24,400	1,610	126

2.2. Flood wall structure

Fig. 5 shows the typical section of the wall composed of the 25H sheet pile core with a concrete cover placed above ground. **Fig. 6** shows the typical plan view of the wall with the 25H sheet pile and re-bar configuration. As mentioned earlier, these sheet piles were pressed into the ground.

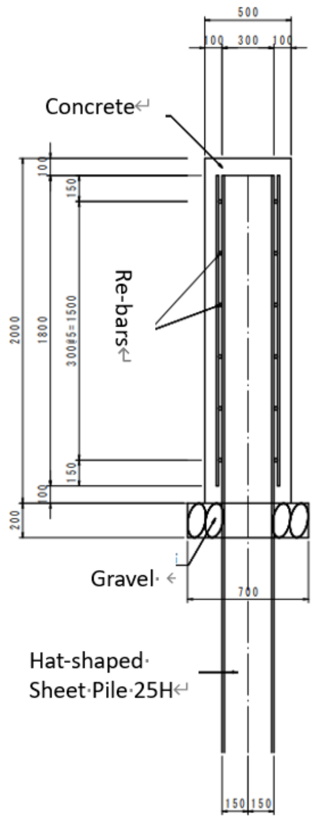

Fig. 5 Typical flood wall cross section with 25H sheet pile

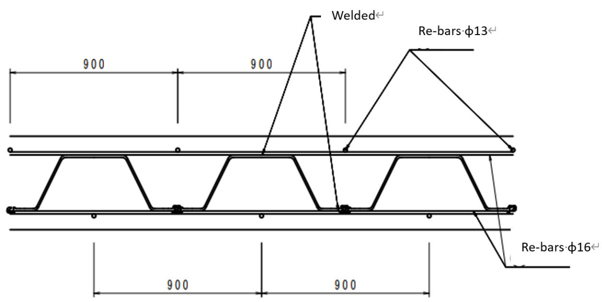

Fig. 6 Typical plan view of flood wall with 25H sheet pile

3. Press-in piling work

3.1 Selection of press-in piling

The press-in piling method was specified to keep the noise and vibration at minimum during sheet pile installation because the piling alignment was on the perimeter of the school campus with the distance only 1 to 3 meters from some of the school buildings and a neighboring house (see **Fig. 7**).

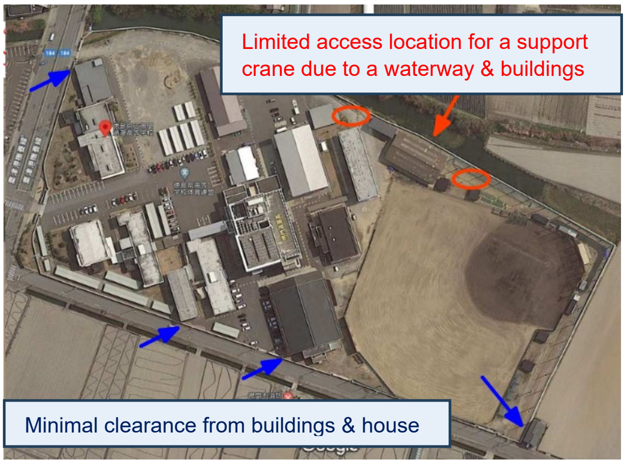

Fig. 7 Flood wall's proximity to school buildings and a neighboring house (Base map: Google Maps)

Press-in piling generates low noise and is practically vibration free compared to conventional piling methods by a large margin (White et al. 2002). A press-in piling machine typically grabs onto previously installed piles to press a new pile into the ground with a hydraulic force as shown in **Fig. 8**. The necessary reaction force (shown in red) against the reactive lifting force (shown in orange color) comes primarily from extraction resistance of already installed piles, the weight of machine, and the piles themselves.

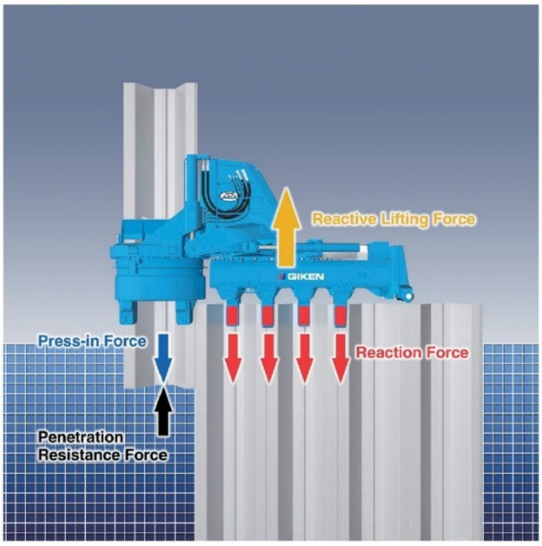

Fig. 8 Principle of Press-in Piling (source: GIKEN LTD.)

3.2 Pile installation work

The flood wall work was executed in three segments; all of which were completed in 2017. The sheet piles were pressed-in without disturbing the students or school staff in front of the school's administration and classroom buildings as shown in **Fig. 9**. The school buildings and their foundations were intact even at their closest points to the piling alignment shown in **Fig. 10**. **Fig. 11** shows a pile installation right next to a house and its concrete block fence. **Fig. 12** shows the sheet piles installed along a waterway before a concrete cover was placed and **Fig. 13** shows the completed flood wall with a concrete cover.

Fig. 9 Sheet pile installation in front of the high school's main entrance

Fig. 10 Sheet piles installed next to school buildings with minimal clearance

Although the authors do not have access to the actual production rate of sheet pile installation, about 20 sheets per 8-hour working day were expected on average based on the soil and other project conditions.

The 2 red ovals shown in **Fig. 7** indicate the locations of a support crane for sheet pile installation behind the buildings tightly positioned next to the pile line. Because of a large operating radius required over the buildings at these locations, hypothetical use of a vibratory hammer would have required a much larger crane than a 50-ton capacity crane used for the press-in piling. A crane for a vibratory installation typically suspends both the hammer and the pile, while a press-in support crane just needs to carry the weight of a pile thanks to the self-walking function of a typical press-in piling machine.

Fig. 11 Press-in sheet pile installation next to a house

Fig. 12 Sheet pile wall installed along a waterway

Regarding sheet pile installation standards for Japan's public works projects, the "Civil Engineering Works Construction Control Standards and Criteria (Proposed)" issued by the Ministry of Land, Infrastructure, Transport and Tourism" is typically referred to. These government specifications require sheet pile installation with 50mm or less as a vertical tolerance and 100mm or less as a horizontal tolerance with no tolerance for shorter penetration than design. There are more stringent criteria proposed for pressed-in piles by the International Press-in Association as shown in **Table 2;** although the authors were not able to verify which standards were applied to this project.

Fig. 13 Flood wall complete with concrete cover

3.3 Prospect for similar future applications

With sea level rising at a fast pace and flooding occurring more often due to more irregular weather patterns than before, the needs for reliable, durable, and economical flood walls, including those against high tides and tsunamis, are increasing worldwide. Steel sheet piles can easily meet these requirements thanks to their design flexibility and fast construction. They can be installed without generating much noise or vibration with press-in piling where needed as exemplified with the case study project. Where construction access to a wall location is limited, the GRB System™ may facilitate the installation (Takuma et al., 2021).

Table 2 Quality control criteria of pressed-in piles
("Pressed-in Earth Retaining Structures: A Handbook, International Press-in Association, 2021)

Management items	Management details	Measuring methods	Standard tolerances	Recommended control values	Measuring frequency
At the completion of pile installation	Driving records	Managed using press-in parameters and press-in data from press-in piling machine terminals	As per drawings and specifications	–	All
	Pile wall length	Measure and manage using a transit compass, etc.	+ one sheet pile, - 0 (Steel tubular piles with interlocks: as per drawings and special notes)	same as on the left (same as on the left)	*
	Top level of pile	Measure and manage the top level of pile swith a spirit level	within ± 50 mm (Steel tubular piles with interlocks: ± 100 mm)	within ± 30 mm (Steel tubular piles with interlocks: ± 60 mm)	*
	Plan position of piles or sheet piles	Measure and manage planar misalignment using a transit compass, etc.	Misalignment in the distance between the centers of piles: within ± 100 mm (Steel tubular piles with interlocks: within 300 mm)	Misalignment in the distance between the centers of piles: within ± 50 mm (Steel tubular piles with interlocks: within 150 mm)	*
	Inclination in longitudinal wall direction	Measure and manage using a transit compass and spirit level	Difference between the top and bottom is less than one sheet pile width, tilt angle within 1/100	same as on the left, tilt angle within 1/150	*
	Inclination perpendicular to the wall direction	Measure and manage using a transit compass and spirit level	Tilt angle within 1/100	Tilt angle within 1/150	*
	Embedded depth	Measure and manage with spirit level	At or above the design value	same as on the left	*
	De-clutching of the sheet pile interlock	Manage via visual inspection	Does not de-clutch	same as on the left	All

* Comply with applicable standards.

4. Concluding remarks

Many school buildings have been renovated to be dual purpose facilities for education and emergency refuge as well as for longer-term refuge in Japan based on the experience from the past major natural disasters. Flood walls with pressed-in sheet piles and concrete covers were built very close to schools/emergency refuge facilities and a house without noise nuisance or vibration-induced damage. Sheet pile installations where construction access is limited may be benefited with press-in piling.

Acknowledgements

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References

Harata, N. et al., 2008. Development of Hat-Type Sheet Pile 900. Nippon Steel Technical Report No. 97, January 2008, pp 11-18.

International Press-in Association, 2021. Pressed-in Earth Retaining Structures: A Handbook Second Edition, Table 4.5.5, page 4-112.

Ministry of Education and Science of the Japanese Government, 2020. Case Studies on Disaster Preventive Functions of School Facilities to be Used as Refuge Vol. 1 (in Japanese). https://www.mext.go.jp/content/20200331-mxt_bousai-000005480_02.pdf

Ministry of Land, Infrastructure, Transport and Tourism of the Japanese Government, 2018. Civil Engineering Works Construction Control Standards and Criteria (Proposed) (in Japanese), Page I-7

Naruto City's Website, Tsunami Refuge Map (in Japanese). https://www.city.naruto.tokushima.jp/_files/00498777/07_muya_r5.pdf

Takuma, T. et al., 2021. Upgrading earthen levees with press-in piling and the GRB System. Proceedings of the 2nd International Conference on Press-in Engineering 2021.

White, D. et al., 2002. Press-in Piling: Ground Vibration and Noise During Piling Installation. Proceedings of the International Deep Foundation Congress, ASCE Special Publication 116.