Press-in technology to recover capacity of bridge pile foundation and application prospect in Vietnam

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ABSTRACT

Recently, in many countries in Southeast Asia including Vietnam and Thailand, the overexploitation of riverbed sand caused the riverbed level in many areas decreased significantly, affecting the stability of the riverbank as well as the construction works on the river. For river bridges, the lowering of riverbed level causes the decrease of pile embedment length of the bridge pier foundation, leading to a reduction of the bearing capacity compared to that of the original design, which can cause damage, even bridge collapse. In this study, the authors propose a new method using sheet pile walls installed by Press-in technology to reinforce the pier foundation for recovering the bearing capacity of the foundation. Model experimental tests were carried out to evaluate the effectiveness of the reinforcement method. The experimental results show that the reinforcement method is remarkably effective in recovering the bearing capacity of the foundation. In this paper, the authors also point out the prospect of Press-in technology in Vietnam.

Key words: *Press-in, bridge foundation, pile foundation, riverbed excavation, resistance*

1. Introduction

In recent years, in many countries in Southeast Asia, including Vietnam and Thailand, the process of riverbed sand exploitation has not been strictly controlled, causing significant lowering of the riverbed level in many areas, affecting the stability of the riverbank as well as construction works on the river. For river-crossing bridge projects, the lowering of the river bed causes the reduction of embedment length of the piles of the bridge pier foundation, leading to a decrease in bearing capacity compared to the original design, potentially causing damage and even bridge collapse.

Fig. 1 is the photo of a damaged bridge named Trung Ha bridge in Vietnam in 2023. **Fig. 2** shows another damged bridge in Thailand that excessively subsided in 2010. A traditional method to repair the damged bridges is adding new piles and expanding the foundation raft of the damged piers. Although this bridge repairing method has overcome the consequences of bridge pier foundation subsidence, it still has not been widely applied to all bridge systems due to high cost and requiring long construction time. Therefore, in this paper, the authors propose a new method to reinforce bridge pier foundations without needing to construct additional piles and expand the foundation raft. **Fig. 3** illustrates the bridge pier foundation reinforcement method of this study, including two main steps as follows: First, use the Press-in method to construct sheet pile walls around the bridge pier foundation that needs reinforcement. Next, use sand or loose material to fill the foundation area inside the sheet pile wall.

Fig. 1 The damaged Trung Ha bridge in Vietnam in 2023.

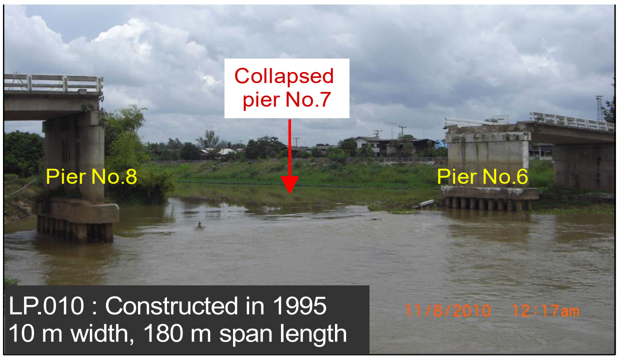

Fig. 2 The damaged LP.010 bridge in Thailand in 2010.

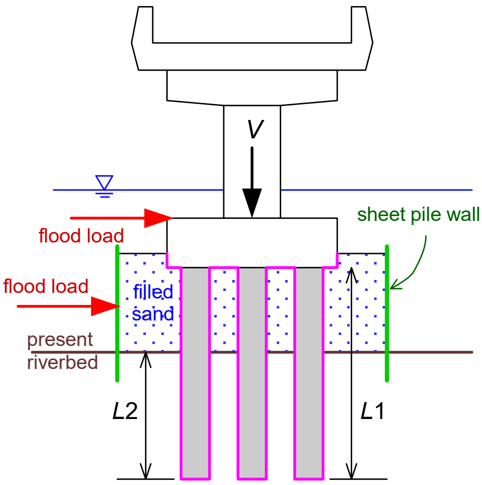

Fig. 3 The reinforcement method using Sheet Pile Wall (SPW).

The Press-in method (see **Fig. 4**) is a method of statically pressing piles that has the ability to minimize noise and vibration during construction, replacing the traditional method of installing piles with hammers or vibratory hammers. The Press-in method can be used in places with extremely limited conditions such as narrow terrain, limited clearance, limited noise, on slopes, and on water... Press-in method assisted with augering and rotary press-in piling have overcome the limitations of the traditional static pile pressing method, which is inapplicable in places with difficult geology such as hard ground, rocks, and gravel. Many studies related to the Press-in method have been conducted such as White et al. (2002), Bolton et al. (2013), Ishihara et al. (2015), Watanabe et al. (2018). However, there are very few studies using the Press-in method to reinforce bridge pier foundations. Therefore, in this study, the authors conducted experimental research in the laboratory to evaluate the effectiveness of using the Press-in method to reinforce bridge pier foundations.

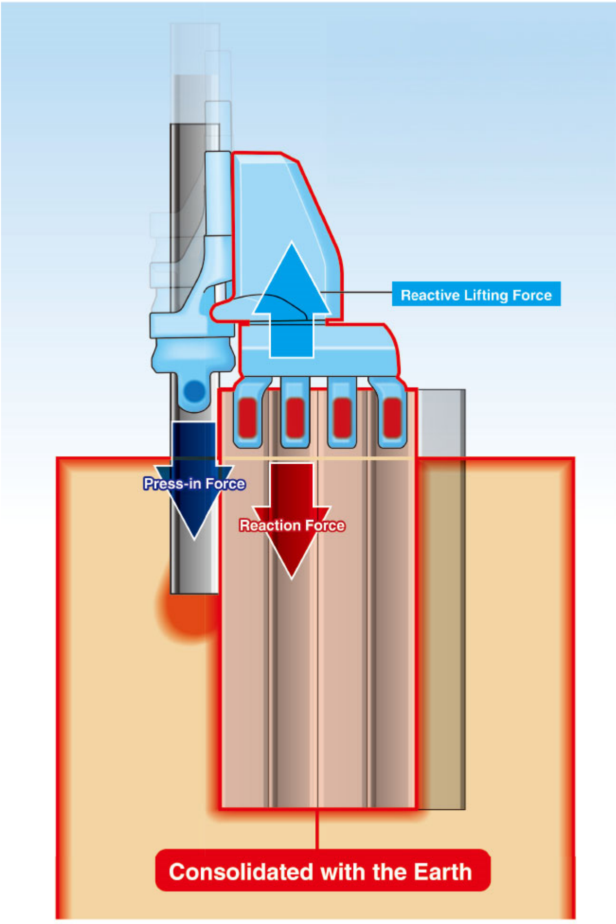

Fig. 4 The Press-in method.

Also, the current situation and future prospect of Press-in piling in Vietnam are presented in this paper.

2. Description of experimental study

The experimental study was presented in Tikanta et al. (2017). It is, however, appropriate to describe the outline of the experiments here again for the convenience of the readers to evaluate the effectiveness of the reinforcement method.

2.1. Model pile foundation

Fig. 5 shows the configurations and dimensions of the 4-pile pile foundation model. The model piles were composed with a pile cap or raft which was made of aluminium alloy JIS A2017. Geometrical and mechanical properties of the pile cap are listed in Table 1. The smaller size model piles having 20 mm diameter with 285 mm length were employed in the load tests on 4-pile pile foundation. Model piles were instrumented with strain gauges along the pile shaft to obtain axial forces, shear forces and bending moments during the load tests. Sand particles were glued on the pile shaft to increase shaft friction and to protect strain gauges from damage. Geometrical and mechanical properties of the model piles are listed in Table 2. Young's modulus, E_p, and Poisson's ratio, ν_p, were estimated from the compression tests of each model pile.

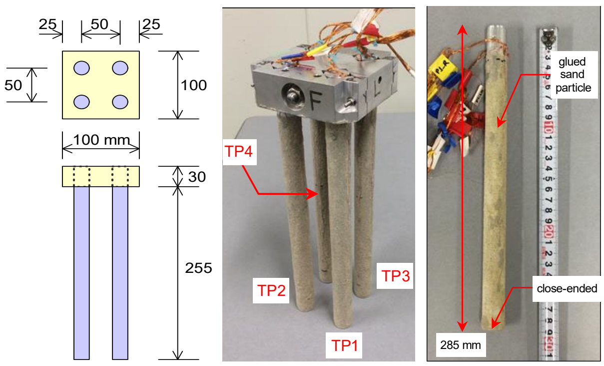

Fig. 5 The pile foundation model.

Table 1. Physical and mechanical properties of the model pile cap

Type of material	Aluminium alloy
Width, B (mm)	100
Length, L (mm)	100
Thickness, t (mm)	30
Pile spacing, s (mm)	50
Normalised pile spacing, s/D	2.5
Density, ρ (g/cm^3)	2.79
Young's modulus, E (MPa)	73,000
Poisson's ratio, ν	0.33

Table 2. Physical and mechanical properties of the model piles

Type of material	Aluminium alloy JIS A6063
Pile length, L (mm)	285
Outer diameter, D_o (mm)	20
Inner diameter, D_i (mm)	17.8
Wall thickness, t (mm)	1.1
Density, ρ (g/cm^3)	2.70
Young's modulus, E (MPa)	65,000
Poisson's ratio, ν	0.33

2.2. Model ground

Dry sand having physical and mechanical properties listed in Table 3 was employed as the model ground for the experiments. The model ground was prepared in several layers to keep a uniform density in a cylindrical model ground container having an inner diameter of 566 mm and a height of 580 mm. The model pile foundation was embedded at the required embedment depth during the process of model ground preparation.

2.3. Model sheet pile wall

PVC (polyvinyl chloride) pipe having 140 mm inner diameter with 135 mm length as shown in **Fig. 6** was employed as model sheet pile wall (SPW) in the reinforcement stage of pile foundation load tests. Geometrical and mechanical properties of the model SPW are listed in **Table 3**.

Table 3. Properties of the model SPW

Type of material	PVC
Outer diameter, D_o (mm)	151
Inner diameter, D_i (mm)	140
Height, H (mm)	135
Wall thickness, t (mm)	5.5
Density, ρ (g/cm^3)	1.415
Young's modulus, E (MPa)	2,100
Poisson's ratio, ν	0.31

2.4. Vertical loading method and the results

Vertical load tests on the pile foundation model were carried out at the initial stage, in the embedment reduction stage (simulating riverbed soil excavation) and in the reinforcement stage. In the embedment reduction stage, the top ground was removed 3 times (1 time of 15 mm excavation and 2 times of 60 mm excavation) as shown in

Fig. 6 (steps No. 2 to No. 4). After the load test at step No.4, the sheet pile wall was set on the ground surface. In the reinforcement stage, the inside of the sheet pile wall was refilled with the sand in 3 steps (No. 5 to No. 7) as shown in **Fig. 7**. In the step No. 7, the pile foundation was recovered to a piled raft foundation where the raft was in contact with the ground surface again. The top sand layer was filled and compacted by steel rod to make the raft contact with the ground surface.

Fig. 8 shows load-settlement curves at the initial stage No.1 and in the embedment reduction steps No. 2 to No. 4. Note here that settlement was zeroed at the start of loading in each step for comparison. It is seen that vertical resistances and initial stiffness of the pile foundation decreased with the reduction of pile embedment length from No. 2 to No. 4. It is also seen that the load-settlement curves in the reduction steps No. 2 and No. 3 exhibit a plunging behaviour and the response in step No. 4 exhibits a softening behaviour, while the response at the initial stage No. 1 shows a progressive failure behaviour. **Fig. 9** shows load-settlement curves in the reinforcement steps No.5 to No.7, comparing with the results at the final embedment reduction step No.4 and the initial stage No. 1. It is seen that the vertical resistance and stiffness of the 4-pile pile foundation increased from step No. 4 to step No. 7 with increasing pile embedment length using the SPW reinforcement. In particular, the vertical resistance at the final reinforcement step No. 7 was much greater than that of the initial stage No. 1 (Tikanta et al. 2017).

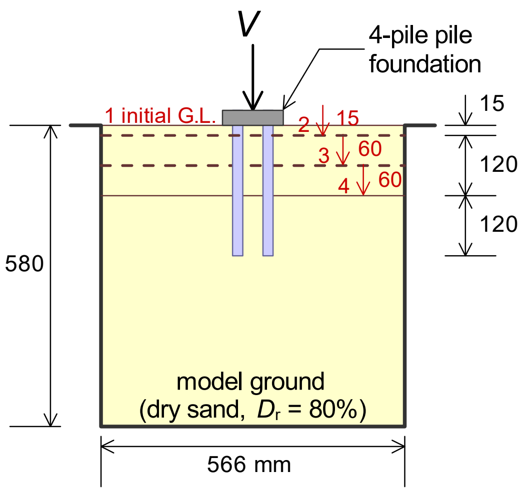

Fig. 6 Vertical load tests at the initial stage and in the embedment reduction stages.

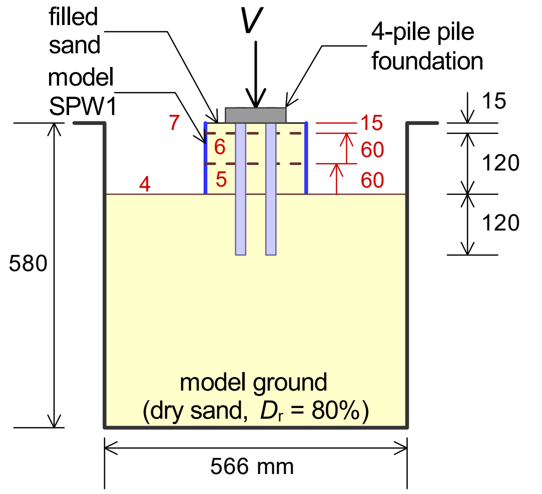

Fig. 7 Vertical load tests in the reinforcement stages.

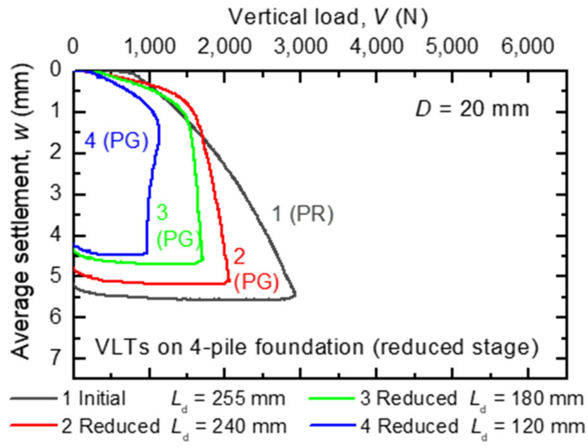

Fig. 8 Load-settlement curves of pile foundation model at the initial stage and the embedment reduction stages (Tikanta et al. 2017).

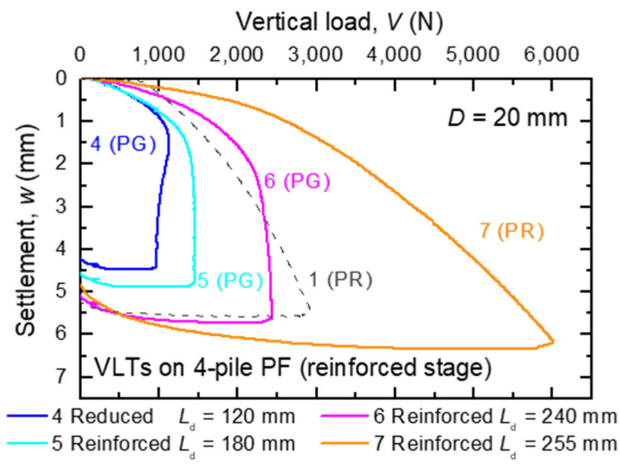

Fig. 9 Load-settlement curves of pile foundation model in the reinforcement stages (Tikanta et al. 2017).

3. Application prospect of Press-in piling in Vietnam

3.1. Current situation in Vietnam

The network of local roads in Vietnam has more than 450,000 km of a total of more than 570,000 km of the national road network (equivalent to 88%) and serving more than 4,300 bridges about 80% of the population and 90% of the poor in the country (Nguyen and Hoang 2020). Lack of this network and low-quality roads and bridges in rural areas is one of the causes of poverty in Vietnam. This has reduced the ability to access social services, especially welfare services (healthcare, education ...), increased transportation costs, limited production transactions. To achieve the goal of poverty reduction and rural modernization, the government has focused on building and maintaining the local transportation system through programs and projects, especially reinforcing thousands of the degraded bridges (**Fig 10**).

Fig. 10 Damaged bridges need reinforcement.

Apart from the lack of road network and low-quality roads and bridges, Vietnam is also subjected to a lot of natural disasters as typhoons, floods and lanslides.

There are about 5 - 6 typhoons and 2-3 tropical depressions affecting Vietnam every year on average. Hurricane season starts in June and ends in late November and the first half of December. Typhoons are most concentrated in August, September, and October. According to statistics over the past 40 years, there are 363 typhoons in the East Sea, of which 143 typhoons made landfall (accounting for 39%); On average, there are 09-10 typhoons and 4 tropical depressions happening in the East Sea every year, of which 4-5 typhoons and 1-2 tropical depressions directly affect the mainland. The number of storms in the East Sea in recent years tends to increase both in number and intensity, for example, 14 typhoons and 5 tropical depressions in 2013, 16 typhoons and 4 tropical depressions in 2017.

Flash floods and landslides often occur in mountainous areas, where there are steep slopes, weak geology, due to heavy rains. According to the survey results of the Institute of Geosciences and Minerals, there are over 10,000 sites with high risk of landslides in mountainous areas. Flash floods and landslides often arise suddenly, occur in a narrow area but very severe consequences, and often cause serious loss of life and property. According to statistics in the last 20 years, there have been over 300 serious flash floods and landslides. This type of natural disaster occurs frequently in mountainous provinces causing serious loss of life and property, but in recent years, there has been a considerable increase in the trend. In the last 10 years (2010 - 2019), the number of flash floods and landslides has increased by nearly 1.5 times (176 compared to 123) compared to the previous 10 years (2000 - 2009), in which in particular:

- The flash flood on 2000 October 3rd in Lai Chau caused 39 deaths; flash flood on 2002 September 20th in Ha Tinh caused 53 deaths; flash flood on 2005 September 28th in Yen Bai, killed 50 people.
- The flash flood on 2016 September 14th in Nghe An caused 12 deaths; flash floods on 2017 August 3rd in Son La and Yen Bai killed 36 people; Landslide on 2017 October 13th in Hoa Binh killed 34 people.
- In 2018, there were 18 severe flash floods and landslides on a large scale in the northern and central mountainous provinces: serious flash floods occurred in Lai Chau province in June 2018, Thanh Hoa province in August 2018, and Khanh Hoa province in November 2018. Flash floods and landslides have left 82 people dead and missing (accounting for 37% of the total loss of life across the country).

- In 2019, flash floods and landslides after the August 3rd storm in the mountainous provinces of the North and North Central region made 22 people dead and missing, of which the most serious was in Quan Son district, Thanh Hoa province left 16 people dead and missing.

- In the first 10 months of 2020, there were 7 terrible landslides that made over 100 people dead and missing, including many officers and soldiers of the armed forces, especially landslides in the Rao Trang 3 hydropower plant (**Fig. 11**), sub-zone 67, Huong Tra district (Hue province), Huong Hoa district (Quang Tri province); Tra Leng and Tra Van communes in Nam Tra My district (Quang Nam province).

Fig. 11 Landslide in Cao Bang province in 2023

Along with flash floods and landslides, riverbank and coastal erosions have occurred quite frequently throughout the country, with an increasing tendency in both frequency, scope, and level of danger, seriously affecting the property of the country and the resident, affecting the people's life and production in the disaster-affected area.

According to reports from provinces/cities, there are 2,358 eroded riverbank and coastline sites in the country with a total length of over 3,133 km. In which, there are 206 points of special landslide (landslide directly endangers the safety of dikes, residential areas and important infrastructure) with a total length of 427 km; especially in the provinces of the Mekong River Delta with 104 extremely dangerous landslides with a total length of 293 km (**Fig. 12**), seriously threatening the lives and properties of the country and people, and causing the loss of about 300 hectares of land per year.

Fig. 12 Riverbank erosion in Dong Thap province of Mekong River Delta

Coastal erosion is a common phenomenon in coastal areas in all three regions of Vietnam, with 397 sections with a total length of over 920 km, of which erosion occurs in 233 sections with a total length of up to 492 km. Particularly, the coastal strip from Quang Nam to Phu Yen has 65 areas including 105 sections that are eroded. According to the investigation and calculation results of a group of scientists from the Institute of Geography and Quy Nhon University, the coast of Quang Nam province has 20 erosion sections of nearly 19 km (see **Fig. 13**); Quang Ngai province has 27 sections of over 35 km; Binh Dinh has 33 sections of nearly 34 km and Phu Yen province has 25 areas with nearly 21 km of erosion.

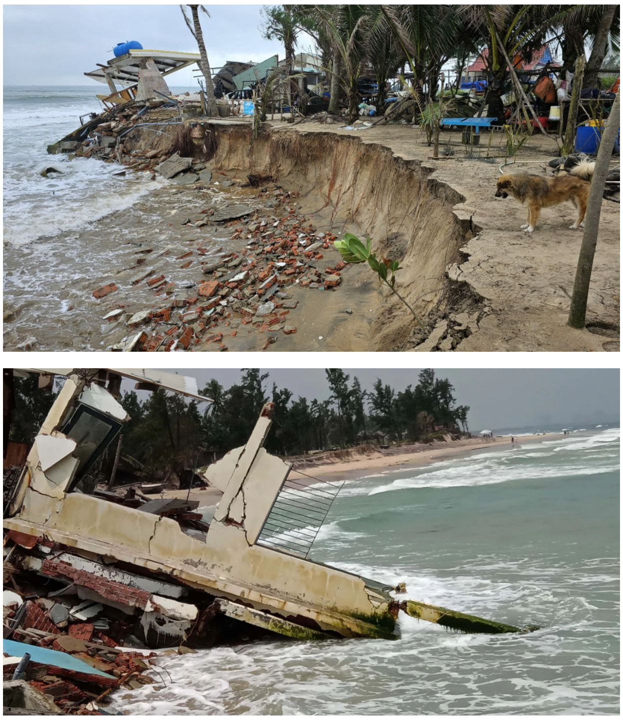

Fig. 13 Coastal erosion in Quang Nam province

3.2. Application prospect of Press-in piling

In Section 3.1, some of the major problems which Vietnam and perhaps many other developing countries are facing have been presented. The problems could be solved effectively if Press-in piling technology is applied, which has been proved through real projects in the world (Bolton, M.D. et al., 2020). Hence, in this section, typical applications of Press-in piling are introduced as effective solutions for overcoming the problems (International Press-in Association, 2021).

Sheet pile walls or tubular pile walls installed by the Press-in piling can be used as deep foundations. A steel tubular pile cofferdam foundation is commonly used, where steel tubular piles with interlocks are installed in series (**Fig. 14**).

Press-in piling can be used to construct embedded structures for coastal protection **(Fig. 15**) in a short time because it does not require a temporary platform.

Stabilizing piles or walls can be used to reinforce existing embankments and prevent landslides (**Fig. 16**). Landslide prevention works utilizing steel tubular piles are widely used as measures against landslides.

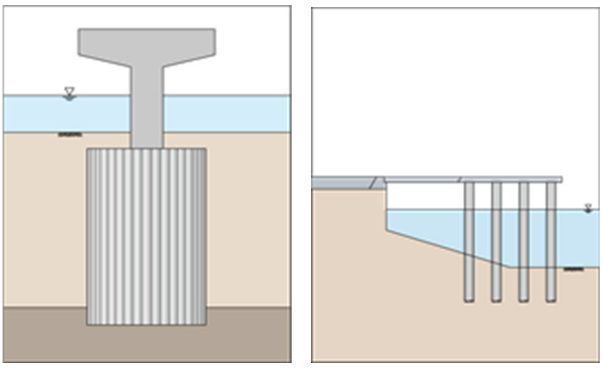

Fig. 14 Bridge pile foundation.

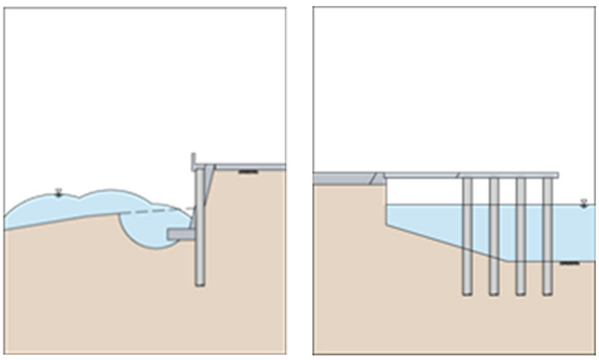

Fig. 15 Coastal protection.

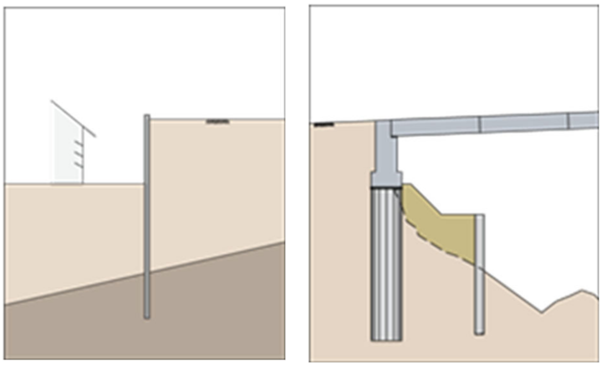

Fig. 16 Lanslide prevention.

4. Concluding remarks

In this paper, a method using sheet pile wall to recover the capacity of bridge pile foundation was proposed. An experimental study to evaluate the effectiveness of the proposed method was presented. Also, in this paper, the authors presented the current construction-related problems that Vietnam are facing and the future prospect of Press-in piling.

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