# Seismic Behavior of the River Embankment Improved with the Steel Sheet Piling Method

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**ABSTRACT**

In recent years, the steel sheet piling method is used as a countermeasure against soft ground for the purpose of reducing the subsidence of the surrounding ground and lateral displacement. Among them, the partial floating steel sheet piling method (called “the PFS method”) constructs a stress blocking wall by alternately placing short-length floating steel sheet piles and long-length conventional steel sheet piles, and is a new construction method to decrease settlement of the embankment side. In addition, it is possible to decrease the subsidence of the ground around the embankment, and it is excellent in terms of workability and economy [1)]. This method has been applied as a subsidence countermeasure for river embankments in Kumamoto Prefecture, Japan. However, in April 2016, a massive earthquake occurred in Kumamoto prefecture that recorded a maximum magnitude of 7.3, causing damage such as subsidence in the embankment of the rivers in Kumamoto plain where the PFS method was used. From these backgrounds, the objective of this paper is to report the damage of river embankment caused by the 2016 Kumamoto earthquake and to evaluate the effectiveness of steel sheet pile structure including the PFS method as an earthquake countermeasure.

***Key words:*** *the PFS method, river embankment, steel sheet piles, earthquake, subsidence*

## 1. Outline of the project

### 1.1. Place

The objective place are the rivers flowting into the Ariake Sea in Kumamoto plain in Kumamoto Prefecture, Japan. Among them, settlement due to the 2016 Kumamoto earthquake was observed especially in the river embankment of the four rivers, the Kase River, the Shira River, the Hamado River and the Midori River.

### 1.2. Background and objectives of the project

The measure applied to the ground subsidence issue of the four rivers is the PFS method which is steel sheet piling method in the river embankment. However, in April 2016, a massive earthquake occurred in Kumamoto Prefecture that recorded a maximum magnitude of 7.3, causing damage such as subsidence in the embankment of these rivers where the PFS method was used. From these backgrounds, the objective of this paper is to report the damage of river embankment by the 2016 Kumamoto earthquake and to evaluate the effectiveness of steel sheet pile structure including the PFS method as an earthquake countermeasure.

## 2. Piling method

### 2.1. Piling method

One of the methods for preventing ground deformation of river embankments on soft ground is the steel sheet piling method. In this construction method, the tip of the steel sheet pile penetrates into the support layer under the weak layer and closes the side of the embankment, for the purpose of preventing the basal destruction of the main body of the embankment and displacement toward the outside of the legs of the embankment [2]).

In the steel sheet piling method, there are different shapes such as the floating steel sheet piling method (called "the FS method") and the conventional steel sheet piling method (called "the CS method"), the PFS method combining the conventional sheet pile and the floating sheet pile. Information such as shaped features of each piling method as exemplified in **Fig. 1** to **Fig. 4**.

Since the FS method does not penetrate into the support layer, construction costs are low, however the effect of suppressing ground deformation is low. Although the CS method penetrates into the support layer, the ground deformation suppression effect is excellent, however the construction cost is high. The PFS method has an excellent effect of suppressing ground deformation by alternately placing the floating sheet pile and the conventional sheet pile, and is excellent in terms of workability and economical efficiency.

### 2.2. Piling type

In the countermeasure work, not only the shape of the steel sheet pile but also the construction position of the steel sheet pile and the kind of countermeasure are changed depending on the object to be countermeasured. A countermeasure for ground subsidence (called "subsidence countermeasure") is applied on the river backside to block the transmission of subsidence to the nearby ground [3]). A countermeasure for earthquake ("earthquake countermeasure") is applied on the river front side to prevent slippage and settlement of the river embankment itself. **Fig. 5** shows the relationship between the CS length of countermeasures $H_1$ and the FS length of countermeasures $H_2$. The straight line in the figure shows the approximate line of the plot data, and the black line, the pink line and the orange line indicate subsidence countermeasure, subsidence & earthquake and earthquake countermeasure. As can be seen from the figure, the subsidence countermeasure and the earthquake counter

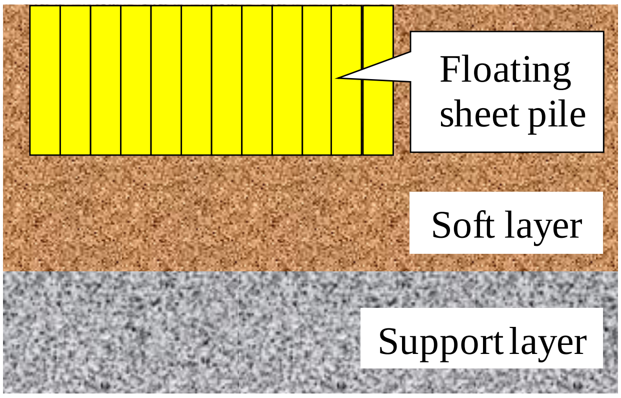


**Fig. 1** The FS method

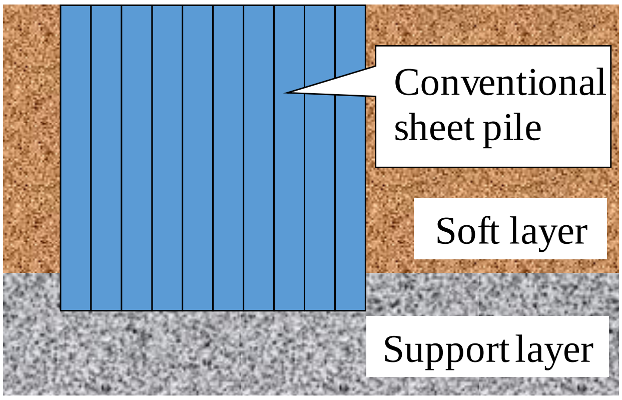


**Fig. 2** The CS method

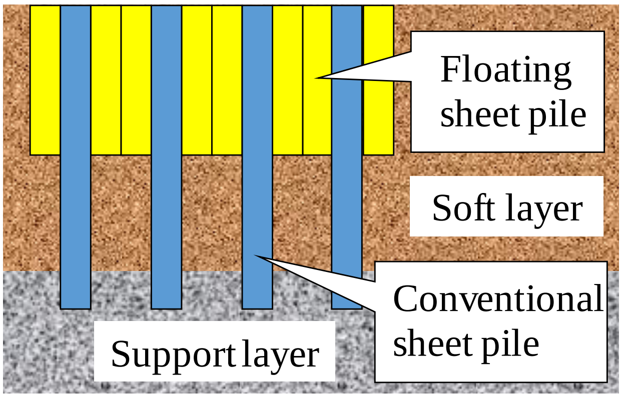


**Fig. 3** The PFS method

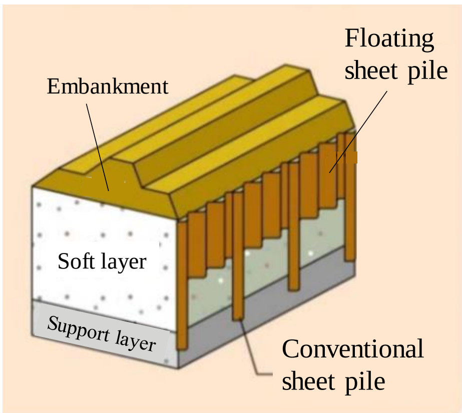


**Fig. 4** Shape schematic of the PFS method

measure are in a linear relationship in which the FS length increases as the CS length increases. There is no clear correlation in subsidence & earthquake countermeasure. In addition, it can be seen that the subsidence countermeasure is longer than the earthquake countermeasure the CS length and the FS length.

### 2.3. Countermeasure working position

**Fig. 6** shows the location of countermeasures in each river in the Kumamoto plain (the Kase River, the Shira River, the Hamado River and the Midori River). Countermeasure working position indicates the river table inside the river levee and countermeasure behind the river outside. The Kumamoto plain has a shallow depth and the alluvial sandy soil layer by the reclaimed land widely distributed.

## 3. Analysis of settlement amount

### 3.1. Layout

**Table 1** shows the shape of each countermeasure and the result of settlement amount measured by the Ministry of Land, Infrastructure and Transport's in river embankment. The amount of settlement is measured at the 200 m pitch of the levee.

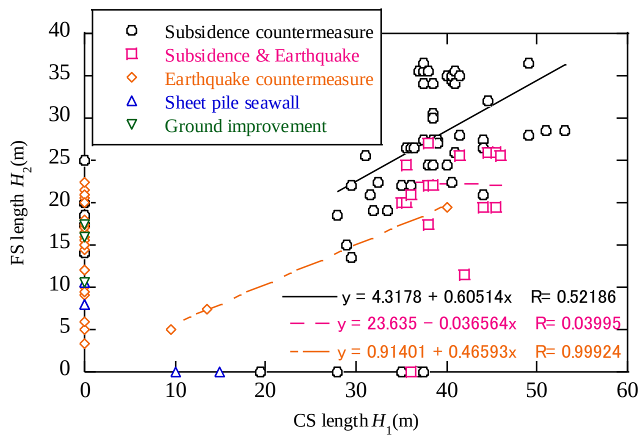


**Fig. 5** Relationship between CS length and FS length

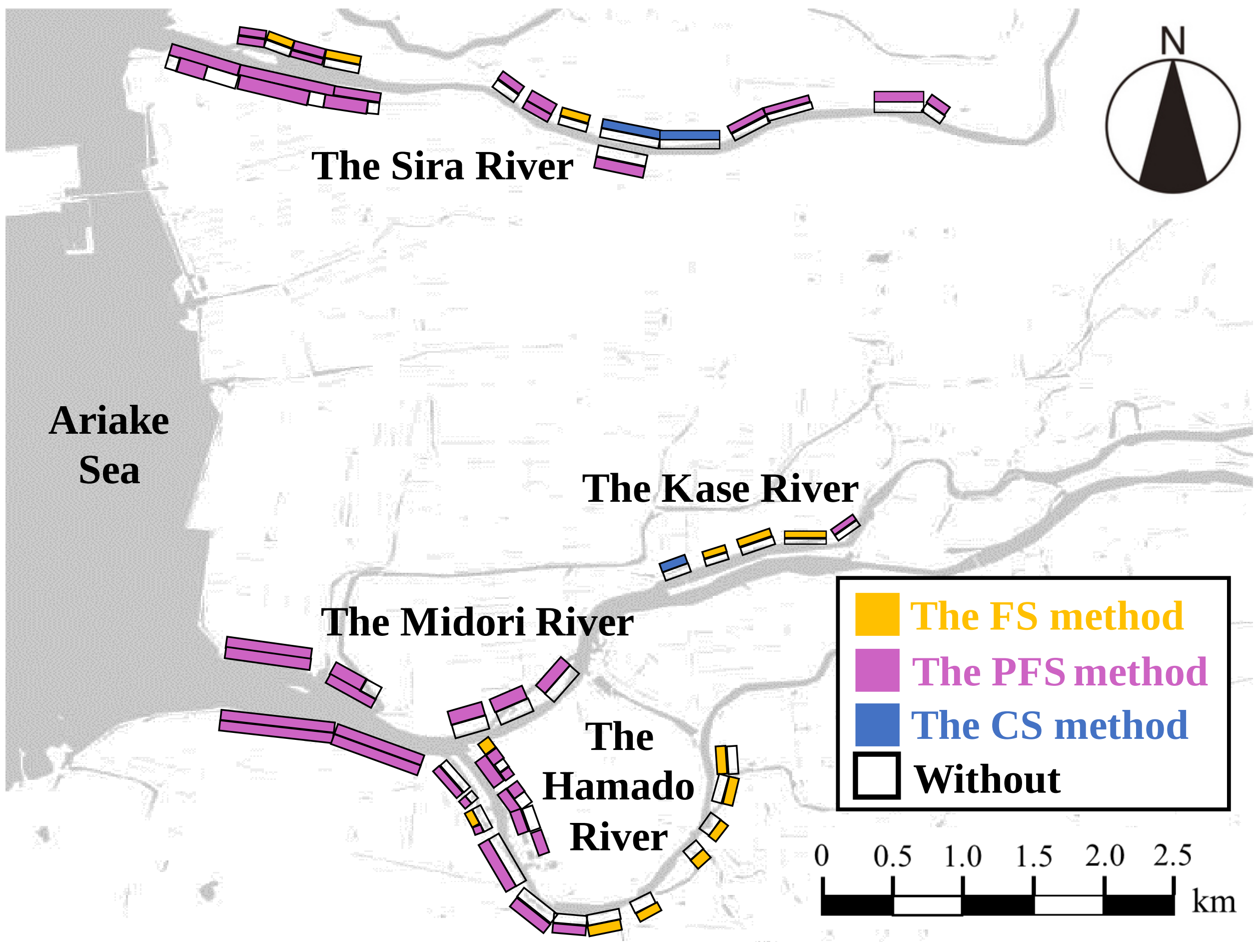


**Fig. 6** Countermeasure working placement position in the Kumamoto plain

### 3.2. Probability density

**Fig. 7** shows the probability density distribution of settlement amount by countermeasures. From the figures, it can be seen that the settlement amount in embankments without countermeasure is distributed over a wide range, whereas the settlement amount of each countermeasure worker concentrates in the range of 0.1 to 0.4 m. In the range of 0.1 to 0.4 m, the FS method is 86%, the PFS method and the CS method is 96%, and the settlement amount is suppressed almost by 0.4 m by the countermeasure work. Focusing on the mode, the FS method and the PFS method were 39% and 46% in the range of 0.2 to 0.3 m, and 57% in the range of 0.1 to 0.2 m, which is the smallest CS method.

### 3.3. Settlement amount range

**Fig. 8** shows the range of settlement amount by countermeasures by percentile plot. This encloses 90% of the population of settlement amount, 95% and 5% above and below the box, 75% and 25% for the upper and the lower broken lines in the box, and 50% for the middle line .As shown in the figure, with regard to the average value, the settlement amount of the CS method is the smallest at 0.106 m, and the unsupervised and the FS method, the PFS method was about the same as the settlement amount around 0.2 m. Focusing on the width of the box, the CS method has the smallest variation, and then the FS method, the PFS method, no countermeasure becomes large. Focusing on the upper and the lower broken line ranges in the box, since the PFS method is located below the box, the settlement amount also concentrates downward. For that reason, it is the PFS method that includes the maximum value of settlement amount in countermeasures, but it can be said that the subsidence amount is larger than the FS method in terms of distribution of the settlement amount. In addition, since the maximum settlement amount without countermeasure is 1.66 m, the countermeasure work is suppressed to less than 0.5 m, so the effect of the ground deformation suppression of the countermeasure worker appears remarkably.

### 3.4. Average settlement amount by countermeasures

**Fig. 9** shows the average settlement amount for each river countermeasure. As can be seen from the figure, in

**Table 1.** The shape of countermeasure and settlement amount

| | | All data | Without | FS method | PFS method | CS method |
|---|---|---|---|---|---|---|
| Settlement amount (m) | Points | 788 | 548 | 53 | 164 | 23 |
| | Average | 0.199 | 0.201 | 0.193 | 0.207 | 0.106 |
| | Mode | 0.210 | 0.210 | 0.150 | 0.170 | 0.100 |
| | Standard deviation | 0.206 | 0.238 | 0.072 | 0.107 | 0.065 |
| | Minimum | -1.184 | -1.184 | 0.060 | 0.008 | -0.070 |
| | Maximum | 1.658 | 1.658 | 0.360 | 0.490 | 0.230 |
| | Measure distance | 142166 | 110903 | 5566 | 23582 | 2115 |
| Conventional sheet pile $H_1$ (m) | Average | - | - | - | 37.9 | 32.5 |
| | Standard deviation | - | - | - | 6.83 | 7.68 |
| Floating sheet pile $H_2$ (m) | Average | - | - | 15.7 | 24.8 | - |
| | Standard deviation | - | - | 4.38 | 6.60 | - |
| Sheet sheet length ratio $H_2/H_1$ | Average | - | - | - | 0.653 | - |
| | Standard deviation | - | - | - | 0.132 | - |

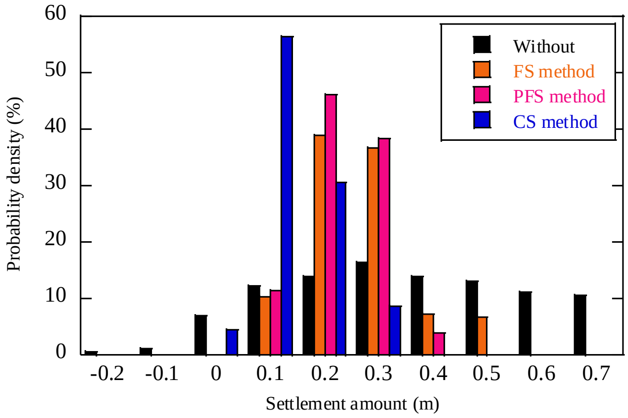


**Fig. 7** Probability density function by countermeasure

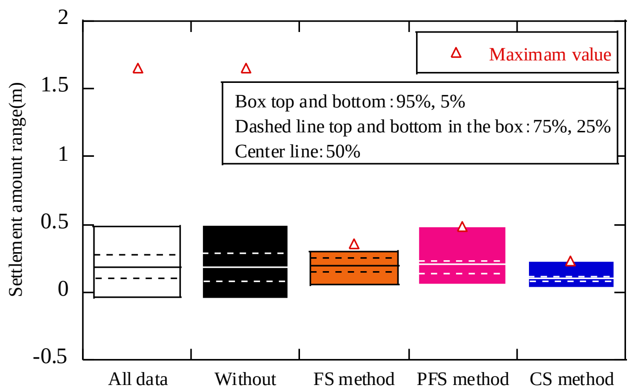


**Fig. 8** Settlement amount range

the Kase River, the Hamado River and the Midori River, the CS method has the smallest settlement amount, then the PFS method, the FS method, without countermeasure and the settlement amount increased. On the other hand, in the Shira River, the PFS method has the largest settling amount, and shows the smallest settlement amount without countermeasure. It is thought that this was influenced by the ground property of each river.

### 3.5. Pile length ratio and settlement amount

**Fig. 10** shows the relationship between the pile length ratio and the settlement amount. We consider the ground suppression effect from the shape of the pile sheet length and the kind of countermeasures in the PFS method by using the index obtained by dividing the FS length $H_2$ by the CS length $H_1$ as the pile length ratio. As can be seen from the figure, the pile length ratio is 0.4 to 0.7 for countermeasures against sinking and about 0.85 for earthquake countermeasure, and the countermeasure against settlement has a big difference between the CS length and the FS length. This is considered to be due to the fact that the countermeasure against settlement was applied in thick sections of the soft ground layer, so that the CS length penetrating into the support layer became longer than the earthquake countermeasure. In addition, most of the settlement amount is less than 0.3 m, and there are no clear difference in the settlement amount depending on the type of countermeasure.

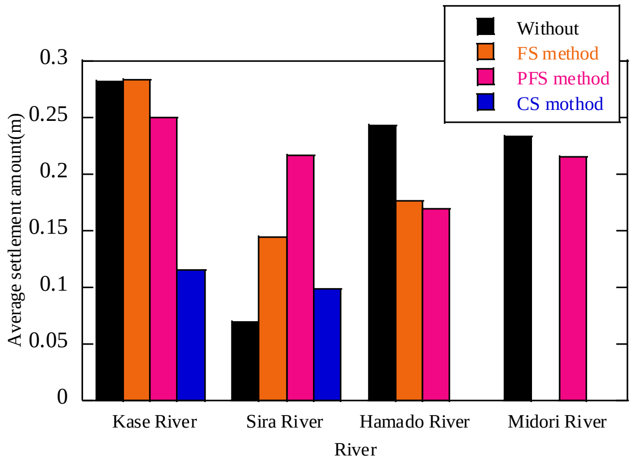


**Fig. 9** Average settlement amount by countermeasures

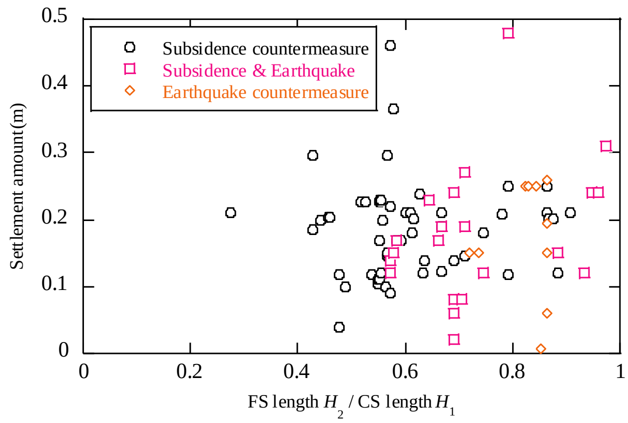


**Fig. 10** Relationship between pile length ratio and settlement amount

## 4. Concluding remarks

The embankment reinforcement method using steel sheet piles are examined for the effect of suppressing ground deformation at the time of earthquake and the findings obtained are described below.

1) Regarding settlement of river levees caused by the Kumamoto earthquake in 2016, the maximum value of each countermeasure was no more than 0.5 m. Maximum effect for reducing deformation was 71 % compared with section provided no countermeasures

2) As for frequency of the settlement, their range was between 0.1 m and 0.4 m. 86 %, 96 % and 96 % of the amount of settlement provided the FS method, the PFS method and the CS method were in the range respectively.

3) Comparing with average value of settlement amount in each countermeasure, the CS method is the smallest 0.1 m.

4) Although it is not clearly understood that the effectiveness of the PFS method is superior to other construction methods, it is necessary to consider the geology at the countermeasure construction site.

## 5. Acknowledgements

This research is proceeding while receiving various opinions from "the Technical Committee on Expansion of Applicable Conditions of International Pressing Association PFS Method and Evaluation of Earthquake Behavior". We would like to express our sincere gratitude to everyone concerned.

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