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A Study on Strengthening Method for Pier Piles using Ultra High Performance-Strain Hardening Cementitious Composite

Ryoichi TANAKA[1*], Minoru KUNIEDA[2], Mitsuyasu IWANAMI[3], Ema KATO[4], Yuichiro KAWABATA[4] and Takahiko AMINO[1]

[1]*Toa Corporation, Japan*
[2]*Gifu University, Japan*
[3]*Tokyo Institute of Technology, Japan*
[4]*Port and Airport Research Institute, Japan*
[*] *〒230-0035, 1-3, Anzen-cho, Tsurumi-ku, Yokohama, Japan*
ryo_tanaka@toa-const.co.jp, kunieda@gifu-u.ac.jp, iwanami@cv.titech.ac.jp, katoh-e@pari.go.jp, kawabata-y@pari.go.jp, t_amino@toa-const.co.jp

ABSTRACT

The lining method for pier piles have been developed using Ultra High Performance-Strain Hardening Cementitious Composite (named as "UHP-SHCC" in this paper) in order to prevent the damage due to disaster and extend the life span of existing piers. The concept of the developed method is to increase flexural load carrying capacity at the pile head and to prevent corrosion of the pier piles between the tidal and splash zone by UHP-SHCC lining with thinner thickness. It is also expected to improve the resistance against crack occurrence of the lining mortar due to the deformation of the pier piles and the resistance against the impact of the driftage. Various experiments have been conducted for verifying the improvement of the above performance. In this paper, the experiment results on the protective performance against steel corrosion and the improvement of the flexural capacity by this method are introduced.

Keywords. UHP-SHCC, pier piles, lining, strengthening, corrosion prevention

INTRODUCTION

Port facilities have important roles of combining the sea and the land transportation and supporting the economic activities of regional community. However, the huge disasters, such as strong earthquake and tidal wave etc., have sometimes occurred in Japan recently. So, there are growing concerns about the social damage when existing port facilities are collapsed by the great disaster. In addition, since most of existing port facilities in Japan were constructed during the high economic growth period, around 1960's, the increment of maintenance costs for these old facilities is also one of the big issues. Therefore, in order to utilize these facilities in good condition for an expected period, it is required to extend the life span of these facilities, as well we to improve the resistance against disaster, necessitating in development the construction technique at low cost.

A pier is one of port facilities. The corrosion prevention system is applied to the surface of steel pipe piles located at the splash and tidal zone, such as surface coating repair technique, mortar lining technique and use of petrolatum tapes with FRP cover (In sea water, cathodic protection with the sacrificial anode is applied). However, these corrosion prevention systems have some problems that loss of corrosion preventive performance sometimes occurs earlier than originally-expected period by deterioration of materials for corrosion prevention or action of accidental external force such as impact of driftage. On the other hand, large bending moment at the pile head (the joint part of the pier piles and the superstructure) is generated by acting not only berthing force and seismic force but also the above accidental force on the pier. Therefore, it is very important for improvement of resistance against disaster to strengthen the pile head particularly.

From these backgrounds, a strengthening method for pier piles have been developed using Ultra High Performance-Strain Hardening Cementitious Composite (M. Kunieda, 2007) [named as "UHP-SHCC" in this paper]. UHP-SHCC has the excellent properties such as high compressive and tensile strength, high toughness and high resistance against penetration of substances, comparing to those of ordinary concrete. In this paper, at first, the features of UHP-SHCC is introduced and then the following experimental results are shown; 1) protective performance against corrosion of steel plates covered with UHP-SHCC, which multiple cracks are generated on the surface, and 2) improvement of flexural capacity of steel pipe piles with UHP-SHCC lining.

FEATURES OF UHP-SHCC

The size and the amount of pores in cement matrix of UHP-SHCC becomes smaller than that of ordinary cement mortar by lower water-binder ratio and addition of silica fume. Furthermore, the tensile strain hardening property of UHP-SHCC is given by addition of high strength polyethylene short fiber (PE fiber). According to the past experiments, it can be verified that UHP-SHCC has the high strength and durability as follows;

The compressive strength over 100N/mm^2, the tensile strength over 8N/mm^2 and the strain at the tensile strength over 2% can be obtained by adding PE fiber of 1.5% versus mortar volume. The results of uniaxial tensile tests and the crack patterns at the tests are shown in Figure 1 (A. Kamal, 2008) as an example. The higher tensile strength and larger strain at the tensile strength can be obtained with more PE fiber content. Also, the number of multiple cracks on the surface of specimen was increased with PE fiber content.

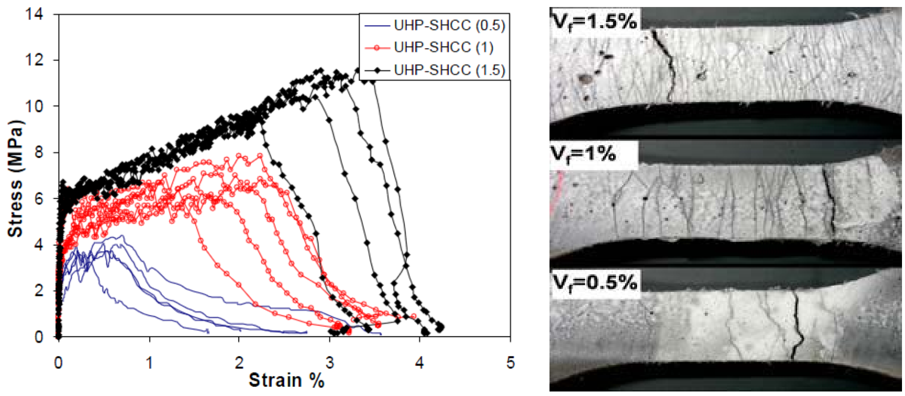

Figure 1. Stress-Strain Relationship and Crack Pattern of UHP-SHCC (A. Kamal, 2008)

The air permeability of UHP-SHCC measured by a Torrent permeability tester was about 1/100 - 1/1000 as low as that of normal concrete with the water cement ratio of 0.56 (M. Kunieda, 2009). The apparent chloride diffusion coefficient of UHP-SHCC, which was obtained by fitting the measured penetration profiles of chloride concentration by EPMA to Fick's second law's equation after submerging the specimens of UHP-SHCC for 6 months in 10% NaCl solution, was about 0.015 to 0.035 cm^2/year, being very smaller than that of normal concrete (H. Hamada, 2009).

OUTLINE OF EXPERIMENT

The excellent protective performance against steel corrosion under marine environments and the enhancing effect of flexural capacity at the pile head by lining the pier piles with UHP-SHCC are required for our developing method.

The outline of examination on the above performance is explained below.

Materials and Mix Proportion of UHP-SHCC. In this study, the materials and the mix proportion of UHP-SHCC shown in Table 1 and Table 2 were used. The mechanical properties of UHP-SHCC used for the experiments were the followings; the compressive strength was 121N/mm^2, the Young's modulus was 27.5kN/mm^2 and the tensile strength was 6.5N/mm^2.

Table 1. Materials of UHP-SHCC

Symbol	Material	Content
W	Tap Water	Density 1.00g/cm^3
C	Ordinary Portland Cement	Density 3.16g/cm^3
SF	Silica Fume	Density 2.20g/cm^3 Specific surface area 200,000cm^2/g
EX	Expansive Additive	Density 3.10g/cm^3
S	Quartz Sand	Density 2.68g/cm^3 (Class No.6)
SP	Superplasticizer	Polycarboxylic acid-based
AN	Antifoaming Agent	Polyether based
PE	High Strength Polyethylene Fiber (PE fiber)	Density 0.97g/cm^3, Diameter 0.012mm Length 6mm, Elastic modulus 88GPa Tensile strength 2700MPa

Table 2. Mix Proportion of UHP-SHCC

W/B	S/B	PE fiber content (vol. %)	Unit weight (kg/m^3)						Admixture (kg/m^3)	
			W	B			S	PE	SP	AN
				C	SF	EX				
0.22	0.10	1.5	347	1301	236	40	158	14.5	31.5	6.9

Specimens for the Experiment on Corrosion Protective Performance. According to the past research, it is considered that the high protective performance against corrosion can be expected by covering the steel with UHP-SHCC because the air permeability and the apparent chloride diffusion coefficient of UHP-SHCC is smaller than those of normal concrete. Also, UHP-SHCC has autogenious-healing properties of cracks (T. Morimoto, 2009).

In this experiment, the protective performance against steel corrosion was investigated when the steel plates (the thickness was 6mm) were covered by UHP-SHCC with the multiple cracks and without cracks. The outline of specimen is shown in Figure 2. The experiment procedure is as follows; as the first step, one side of steel plates was covered with UHP-SHCC after sandblasting and welding 2 deformed steel bars (D13) on the contact surface with UHP-SHCC. Next, the multiple cracks on UHP-SHCC surface were generated by flexural loading as shown in Figure 3. In this experiment, the strain of 0, 0.5 and 1.5% on the surface of UHP-SHCC between the bending span of 100mm is given to each specimen respectively (the residual strain of 0, about 0.25% and about 0.5% after flexural loading is confirmed respectively). After that, all the surfaces of each specimen except for the cracked surface of UHP-SHCC were covered with epoxy resin, and then the specimens had been exposed for about 1 year in splash zone, using a underneath open-space of superstructure of a pier located at Yokosuka, Tokyo bay, Japan. After the 1-year exposure, polarization resistance was measured for each specimen at the location shown in Figure 2. Finally, the corrosion state of the surface of steel plates and the welded bars was observed by removing UHP-SHCC from the steel plate.

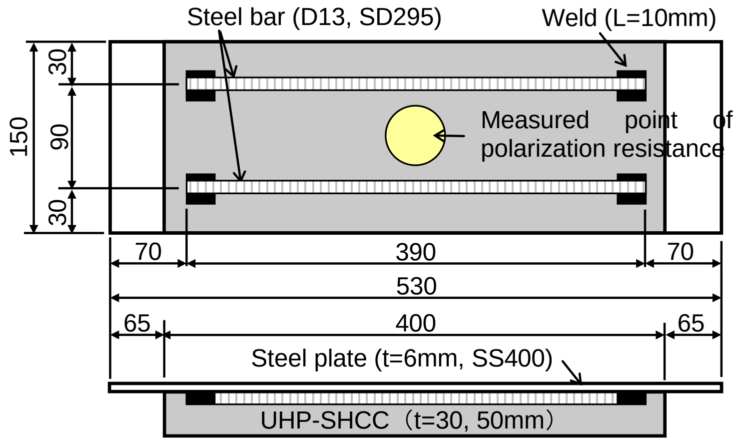

Figure 2. Specimen and Test Position

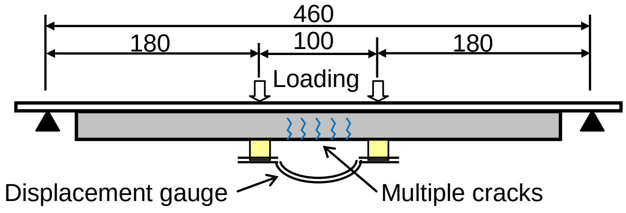

Figure 3. Loading for Inducing Multiple Cracks

Specimens for the Experiment on Strengthening Effect. The applicability of the strengthening methods in which the UHP-SHCC lining and the superstructure of the pier is united at the pile head, as shown in Figure 4, has been examined in order to make the tensile strain hardening property of UHP-SHCC bring out and to occur the multiple cracks effectively.

In this experiment, in order to recognize the improvement of flexural load carrying capacity in the section at the pile head, a loading test by small scale specimen was conducted as shown in Figure 5. The section at the UHP-SHCC lining portion is shown in Figure 6. UHP-SHCC with the thickness of 21mm were lined around a steel pipe of ϕ 89.1mm with 4 steel bars (D6) welded on the surface. Moreover, in order to confirm the effect of the tensile strain hardening property of UHP-SHCC, two types of the strengthened structural details at the pile head (proposed lining method and traditional lining method) were examined, as shown in Figure 7.

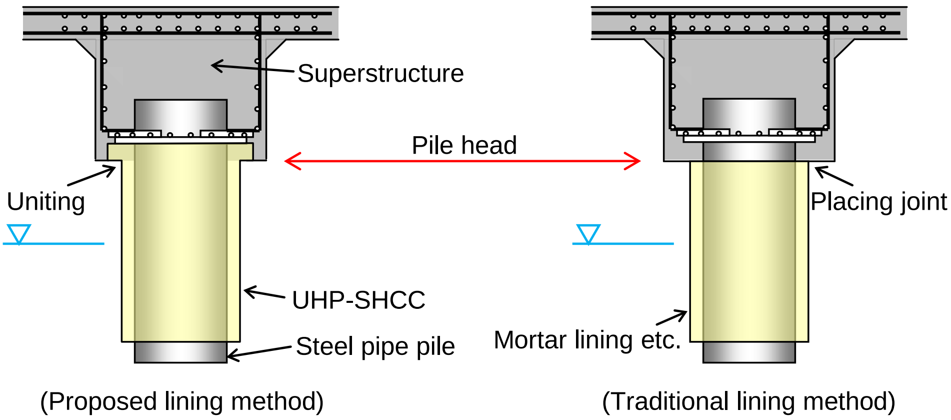

Figure 4. Outline of Strengthening Methods

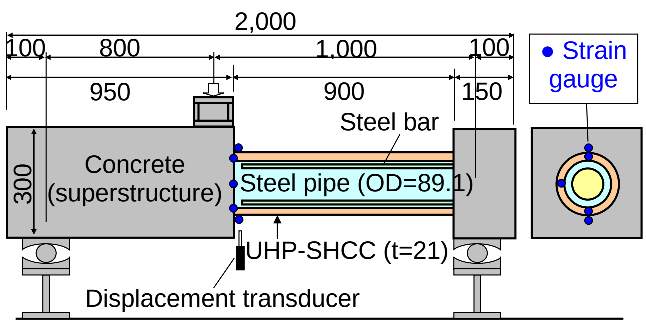

Figure 5. Specimen Configuration and Outline of Loading Test

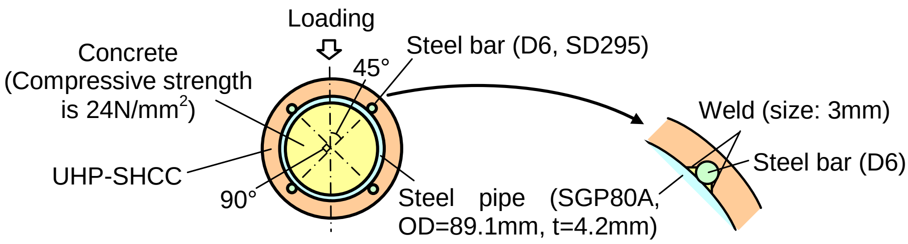

Figure 6. Section of UHP-SHCC Lining Portion

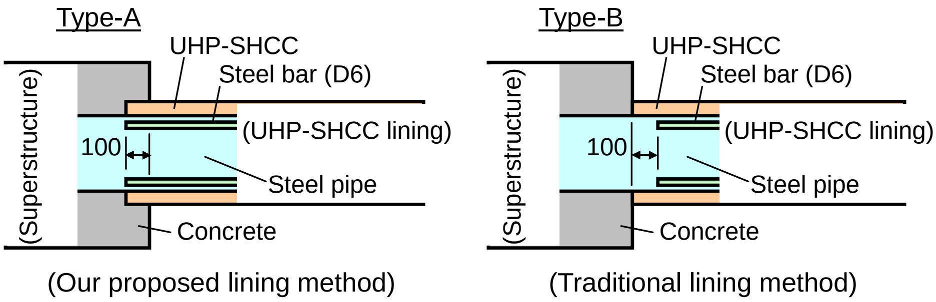

Figure 7. The Strengthened Structural Details at Pile Head

EXPERIMENTAL RESULTS

Corrosion Protective Performance. The measured polarization resistance by an AC impedance method are shown in Figure 8. As seen in this graph, the values of polarization resistance for all the specimens were almost the same not depending on the existence or nonexistence of cracks on the exposure surface of UHP-SHCC. Note that the measured values could be judged as “Passivation (Non-corrosion)” based on the criterion of CEB.

Moreover, after separating UHP-SHCC and steel plate, and the situation of chloride ion penetration in UHP-SHCC and the corrosion on the surface of steel plate were observed. These results are shown in Figure 9. Chloride ion penetrated to the depth of welded steel bars through cracks in case of UHP-SHCC with cracks, while chloride ion penetrated to the depth of about 3mm from the surface in case without cracks. However, even when the lining thickness of UHP-SHCC was 30mm and there were the multiple cracks on the surface of UHP-SHCC, the very slight corrosion was observed on the surfaces of welded steel bars and the corrosion was not observed on the surface of steel plates. On the other hand, the corrosion situation of steel bar in the normal concrete specimen with 0.2mm of crack width is shown in Figure 10. The specimen had been exposed for about 1 year in the same position of the specimens shown in Figure 2. As seen in this Figure, remarkable corrosion was observed on the surface of steel bar at the cracked position. Therefore, it was recognized that the steel corrosion can be progressed drastically slowly by the existence of UHP-SHCC lining even if the multiple cracks occur on the surface of UHP-SHCC due to external forces acting on the pier and the steel covered with UHP-SHCC is exposed under severe corrosive conditions. The follow-up survey on the protective performance against the steel corrosion by this method will be conducted continuously.

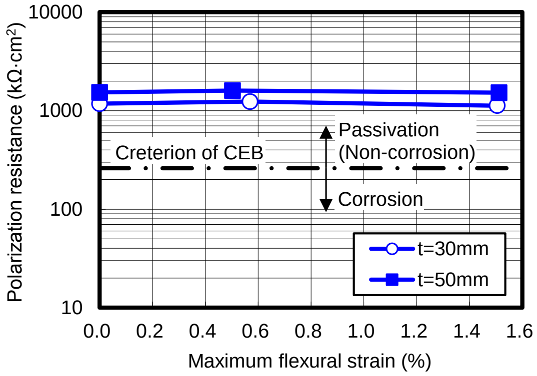

Figure 8. Polarization Resistance vs Maximum Flexural Strain

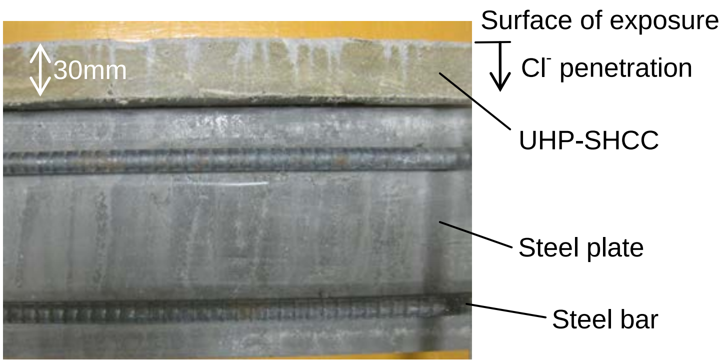

Figure 9. Situation of Chloride Penetration and Corrosion on Steel Surface

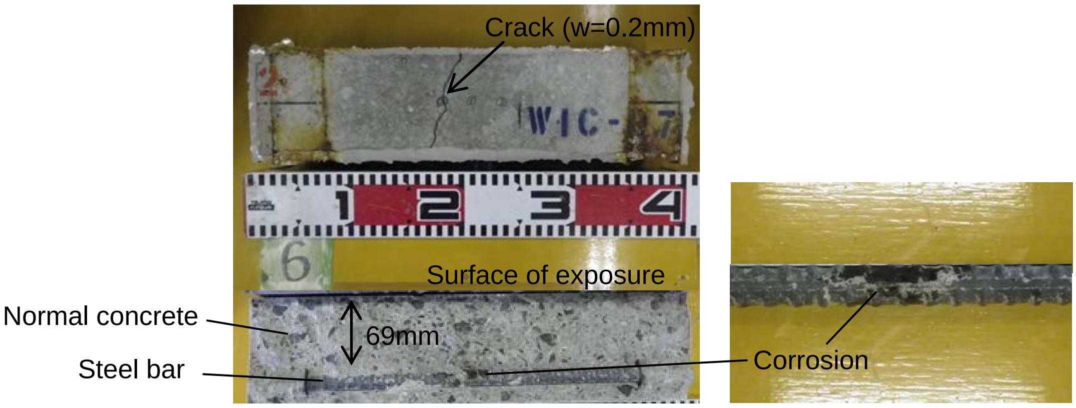

Figure 10. Corrosion of Steel Bar in Normal Concrete

Strengthening Effect. The relationship between the bending moment and the curvature in the section at the pile head is shown in Figure 11. From the result, the flexural capacity in case of Type-A, our proposed lining method, drastically became larger than that in case of Type-B, the traditional lining method. Figure 12 shows the strain distributions at the time of bending moment of 15kN・m, at which the bending moment of the section in case of the traditional method reached the maximum flexural capacity. According to this figure, the strain at the tensile end of steel pipe had remained to be elastic in case of Type-A, while that had become plastic in case of Type-B. From the fact, it was verified that the tensile strain hardening property of UHP-SHCC was made to bring out by the application of our proposed lining method.

Cracking patterns after the flexural loading test around the pile head for each specimen are shown in Figure 13. The multiple cracks had occurred on the surface of UHP-SHCC in case of Type-A, while the large opening was confirmed at the joint of pile head in the case of Type-B. The reason of the large opening in the case of Type-B is not united superstructure and UHP-SHCC. The remained opening between superstructure and UHP-SHCC at the pile head is not allowed from the view point of corrosion protection of steel piles, after external forces acts on the pier. Therefore, in order to improve the resistance of the existing pier against disaster and to extend the service life period, it is considered that it is better to apply strengthened structural details at the pile head such as Type-A. However, it is considered that more examinations on the details of the strengthening method for the pile head will be required.

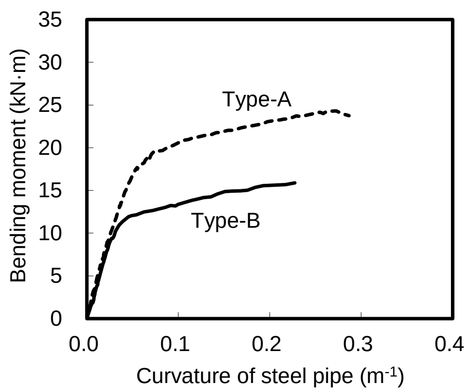

Figure 11. Relationship between Bending Moment and Curvature

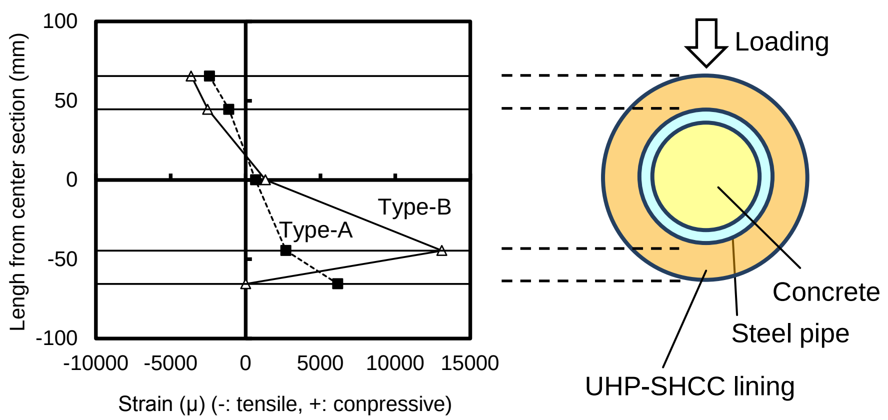

Figure 12. Strain Distribution

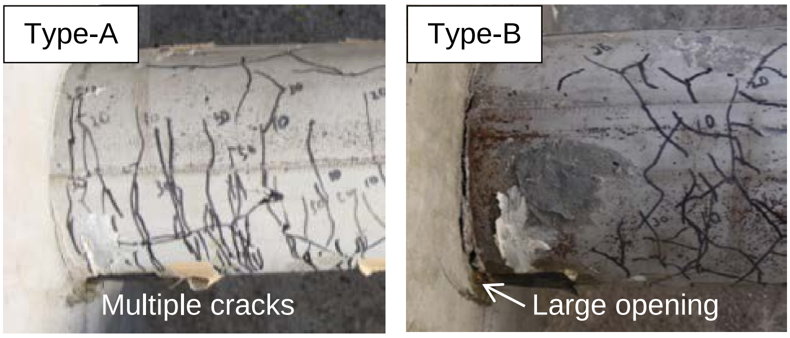

Figure 13. Situation of Crack Occurrence around the Pile Head

CONCLUSIONS

In this paper, the lining method for pier piles using UHP-SHCC was introduced in order to prevent disaster and extend the service life period of existing piers. Also, the concept and the experimental results of the proposed strengthening method were introduced. By the application of the strengthened structural details at the pile head, in which UHP-SHCC lining and superstructure of existing pier was steadily united, the flexural capacity was drastically improved due to the tensile strain hardening property of UHP-SHCC. The authors will continue the investigation on this strengthening method, by conducting more flexural loading tests using actual-sized specimens and construction tests on this method to actual-sized steel pipe piles at existing piers in order to establish this strengthening method.

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