

Appendix-2: System of Inspection and Diagnosis for Port Structures Using an Unmanned Boat

1. Introduction

Presently, the aging of port facilities is progressing in Japan, and it is expected that more than 60% of the facilities will exceed 50 years since construction in the next 20 years. It is necessary to maintain and upgrade the facilities efficiently. However, the problem is that it is difficult to inspect the lower part of the piled piers, which exist in large numbers in Japan, due to the restriction of time and space. Furthermore, in the method of classifying the deterioration condition of the piled piers, the degree of deterioration of the members is judged by humans based on the four-stage standard criteria in Japan. However, it could lead to variation owing to individual differences. For these reasons, we have developed an inspectional method using an unmanned boat equipped with a camera. In addition, 3D model creation technology and crack extraction techniques from photographed images have been established. Also, the diagnostic method to automatically determine the degree of degradation of the members has been developed. In this paper ¹⁾, we have introduced and applied these technologies to an unloading piled pier, which has been 45 years, and have confirmed its usefulness by comparison with the method of inspection and diagnosis by humans.

2. Technical overview

2.1 Inspection Method

The inspection method uses an unmanned boat as shown in Figure 1, to investigate the lower part of a piled pier, as shown in Figure 2. The size of the unmanned boat is 2.2m in length, 1.1m in width, and 0.65m in height. If the clearance under the piled pier is around 80cm, it is possible to use the unmanned boat for investigation. The method of shooting the lower part of the piled pier is to run the unmanned boat on the sea surface and shoot a video with a high-resolution camera. However, in the case of shooting with a camera mounted on the unmanned boat directly, it was found that shaking due to waves caused blurring of images, and that the rolling and pitching motions of the unmanned boat made it impossible to shoot the planned portion. A high-performance gimbal stabilizer as a shaking suppression device was installed with the camera to solve these problems. In addition, LED modules were installed on the unmanned boat since light does not enter the space under the piled pier. As a result, suitable illuminance could be obtained for shooting. For the operation of the unmanned boat, a wireless device that operates in the 2.4 GHz band was employed for short communicable distances in this system. In addition, as an emergency radio equipment, a 350MHz band wireless device was selected. This device is available for long communicable distances, although its communication delay becomes large. Figure 2 shows the illustration of an operator on the ground receiving the camera image transmitted from the unmanned boat under the piled pier using frequency of 5.6GHz band.

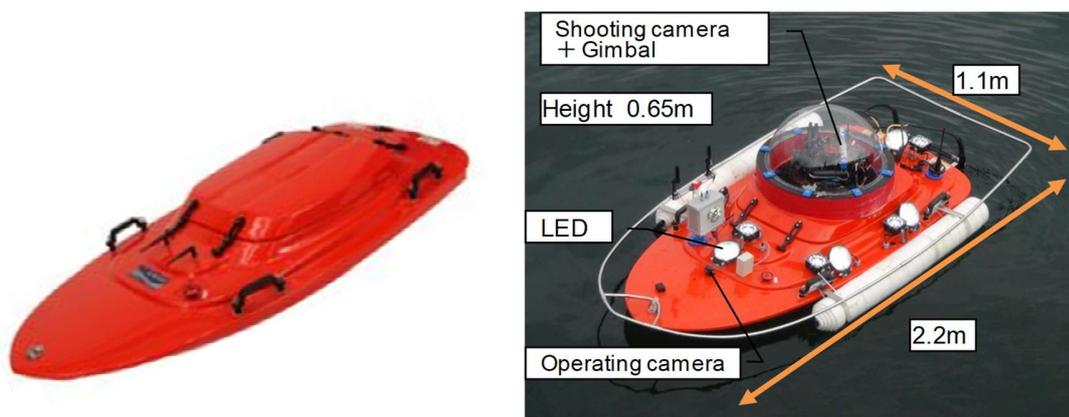


Figure 1 Unmanned boat (left; before mounting the devices, right; after mounting the devices)

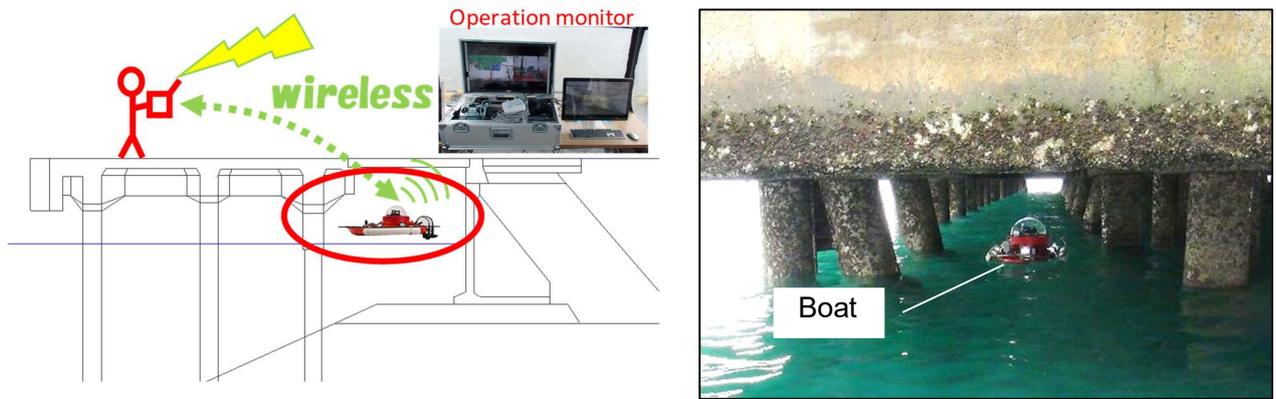


Figure 2 Inspection status under the piled pier

2.2 Diagnosis method

The post-processing of the photographed image is conducted following the flow as shown in Figure 3. First, the photographing position was estimated, and a real 3D model by Structure from Motion / Multi View Stereo (SfM / MVS) analysis was created since no position information can be obtained from GNSS under the piled pier. The SfM / MVS analysis is a method of simultaneously restoring the 3D model and the camera position from a plurality of captured images while changing the viewpoint of the camera. By the constructed 3D model with this method, the relative position of the deteriorated parts such as cracks and rust water can be specified. Thus, it becomes easier to grasp the deterioration state of the structure through SfM / MVS analysis. Next, orthochromatic images of each member were extracted from the 3D model, and the deteriorated areas, such as cracks and rust water were extracted from the orthochromatic image as shown in Figure 4. An example of extracting deteriorated portions is shown in Figure 5. Based on the results, the degree of deterioration of each member was determined in four stages according to the judgment criteria shown in Table 1. Furthermore, the results which were obtained from the analysis, a deterioration diagnosis being conducted for the entire piled pier. Moreover, it is possible to make a prediction of degradation and timing of maintenance in the future by utilizing a database created from the obtained images and related information or by managing the degradation changes over time.

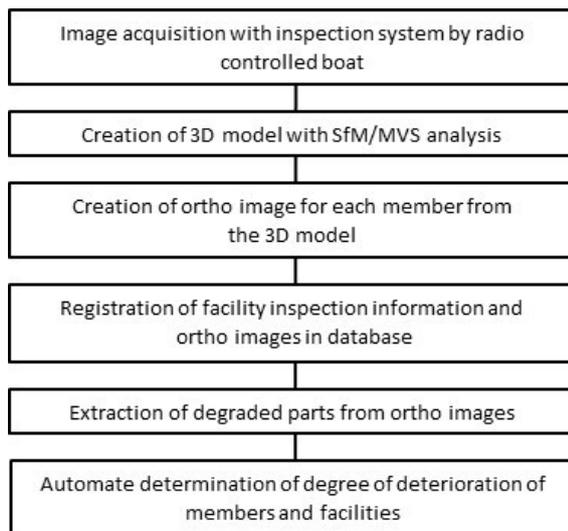


Figure 3 Flow of diagnosis data processing

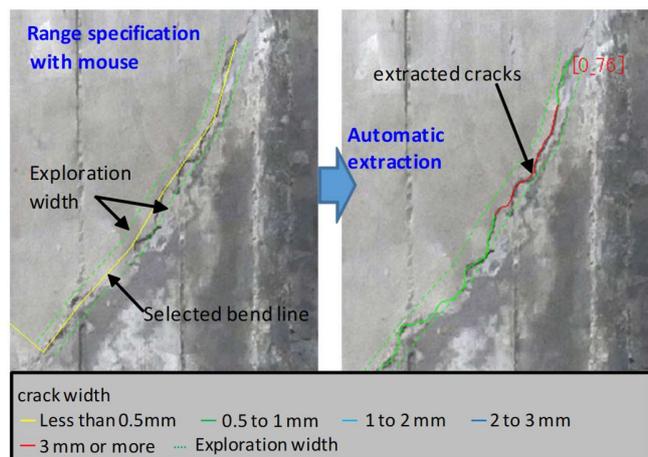


Figure 4 Cracks extraction method

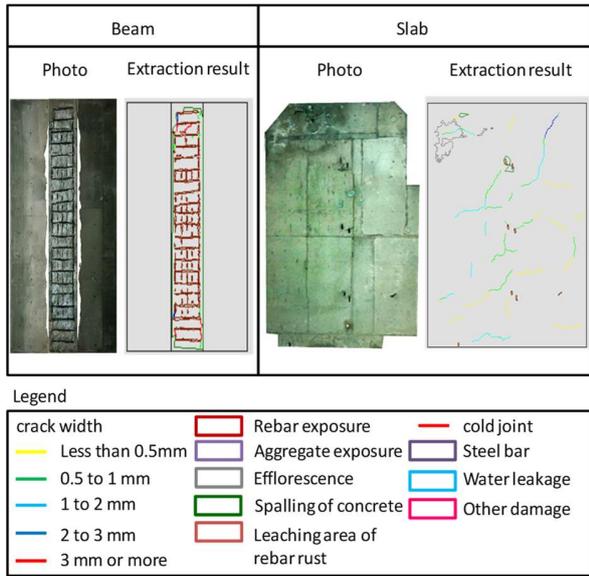


Figure 5 Result of the extraction of the deteriorated part

2.3 Field trial test

The field trial test was carried out in an unloading piled pier constructed 45 years ago, which has 80 m in length and 20 m in width, as shown in Figure 6. The results are compared and verified with the human inspection system. As shown in Figure 7, the unmanned boat was operated to shoot the entire lower part of the piled pier. As a result, it was possible to finish taking pictures of about 1,600 m² in 2 hours. It was found to be improved 2.5 times over the standard inspection method by humans in Japan. Additionally, the 3D model of the entire lower part under the piled pier was created by means of 2,064 images (8,290,000 pixels). The created 3D model is shown in Figure 8. Also, the result from the method of automatically determining the degree of degradation was compared to the method of judgment by humans. Finally, a better coincidence is shown in Figure 9, 100% (54 members / 54 members) for the slab and 90% (116 members / 129 members) for the beam.

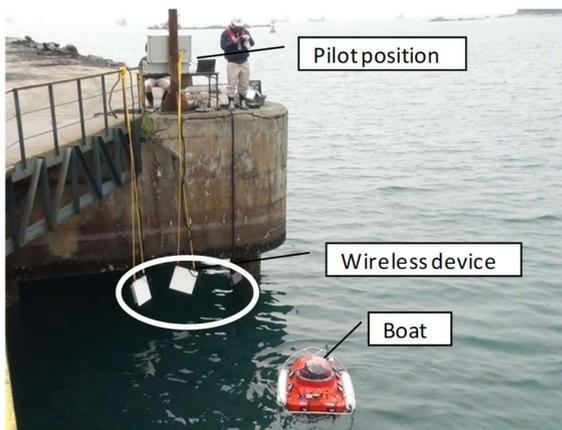


Figure 6 Inspection of the piled pier

Table 1. Degradation degree criterion

(a) Slab		
a	Crack density	2m/m ² or more
	Concrete spalling area	1% or more
	Leaching area of rebar rust and Exposed rebar area	50% or more
b	Crack density	1m/m ² to 2m/m ²
	Leaching area of rebar rust and Exposed rebar area	20% to 50%
c	Crack density	1m/m ² less than
	Efflorescence area	5% or more
	Leaching area of rebar rust and Exposed rebar area	20% less than
d	Other damage	Exist
	Other damage	non-Exists

(b) Beam		
a	Crack in the axial direction of the reinforcing bar with a width of 3 mm or more	Exist
	Concrete spalling area	1% or more
b	Leaching area of rebar rust and Exposed rebar area	50% or more
	Crack in the axial direction of the reinforcing bar with a width of 3 mm less than	Exist
c	Leaching area of rebar rust and Exposed rebar area	20% to 50%
	Crack other than reinforcement axial direction	Exist
d	Leaching area of rebar rust and Exposed rebar area	20% less than
	Other damage	Exist
	Other damage	non-Exists

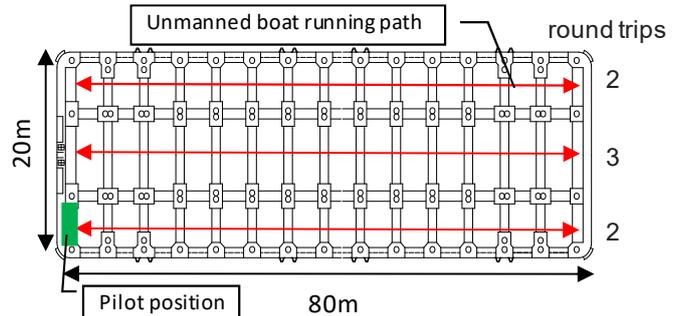
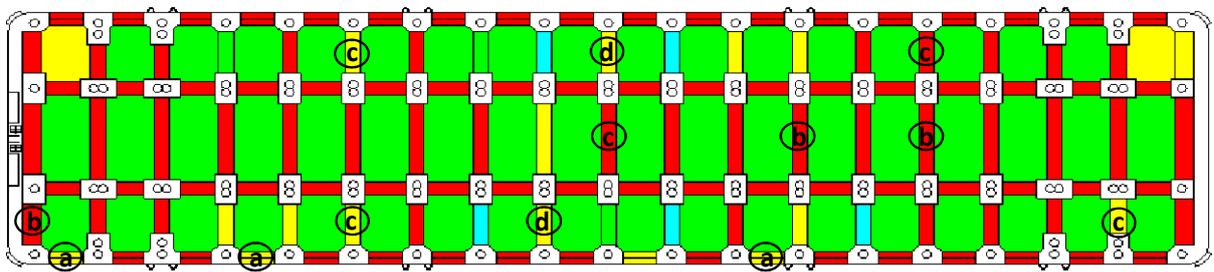


Figure 7 Plane of the piled pier



Figure 8 3D model of the piled pier (View from below)



■ a ■ b ■ c ■ d

The alphabet in the circle is different from the visual inspection by a person

Figure 9 Degree of degradation determination (View from below)

3 Conclusion

We have developed the inspection method using an unmanned boat and the diagnosis method, and applied these technologies to the piled pier. From the field trial test, the results of the diagnosis of the developed system and the standard system in Japan showed good agreement. Furthermore, the efficiency of the developed system was found to be 2.5 times. The usefulness of this system has been confirmed.

References

- 1) Kenichi Mizuno: System of Inspection and Diagnosis for Port Structures Using Unmanned Boat, PIANC Yearbook, PIANC, pp.3-20, 2018.