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Inspection and Repair Technologies for Corrosion-Damaged Port Steel Structures

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Introduction

To keep port/harbor steel structures in a satisfactory condition with less maintenance cost, a maintenance cycle of inspection, condition evaluation, repair/strengthening, and record keeping should be repeated during the design service life of a structure. In this article, an efficient inspection method to measure thickness of steel members and a repair design for corrosion-damaged steel pile piles to recover seismic performance are discussed.

Inspection and Condition Evaluation

Corrosion reduces a cross-sectional area of steel members, leading to a decrease in load carrying capacity. Therefore, to evaluate a current condition of steel structure, a thickness measurement of steel members should be conducted during an inspection. The most popular thickness measurement method is the ultrasonic testing method (UT), which yields an accurate measurement, but requires a surface preparation to remove marine growth, coating and rust prior to measurement. Since the surface preparation needs time and resources, more efficient thickness measurement methods are desired.

One of such efficient thickness measurement methods is the pulsed eddy current testing method[1)] (PEC), which does not require the surface preparation since PEC uses a pulsed magnetic field to produce eddy currents in the surface layer of steel plate. PEC has been used to detect corrosion in pipelines, risers, and insulated pipes. It is said to give an average thickness of a certain area called *footprint*, and therefore, it is usually used in a screening process of inspection. After detecting corrosion by PEC, a more accurate measurement is usually conducted by removing surface coating and rust.

PEC Thickness Measurement

To examine a feasibility of PEC thickness measurement for underwater inspection work of port steel structures, the field thickness measurement[2)] of steel pipe piles by PEC was conducted at a quay in the Port of Nagoya, and the results were compared with values from UT. Fig. 1 shows the measured pipe piles. The quay was 41.5 years old at the time of measurement. Since the subsea zone of piles has been cathodically protected, and the atmospheric, splash, and tidal zones of piles have had coating protection, severe corrosion damage was not observed for these piles.

Measurement was done by PEC first. Then the surface of piles was cleaned to remove marine growth and rust, and

Fig. 1 Measured Pipe Piles

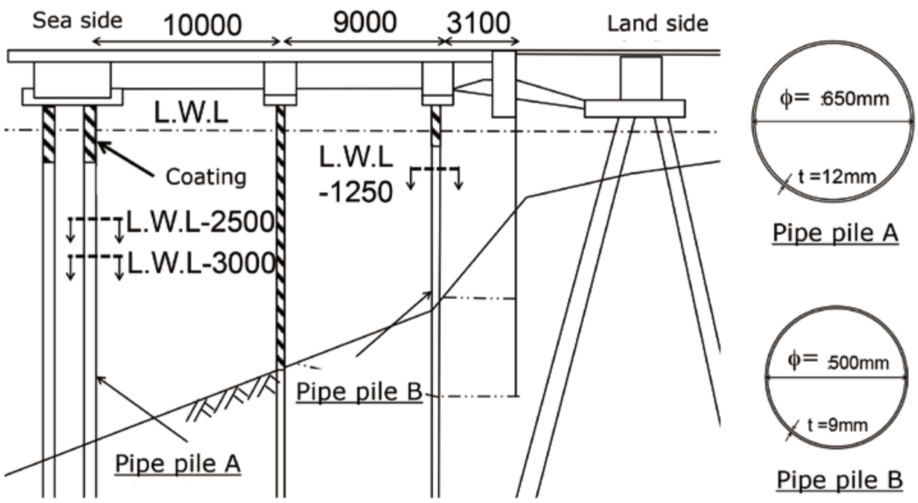
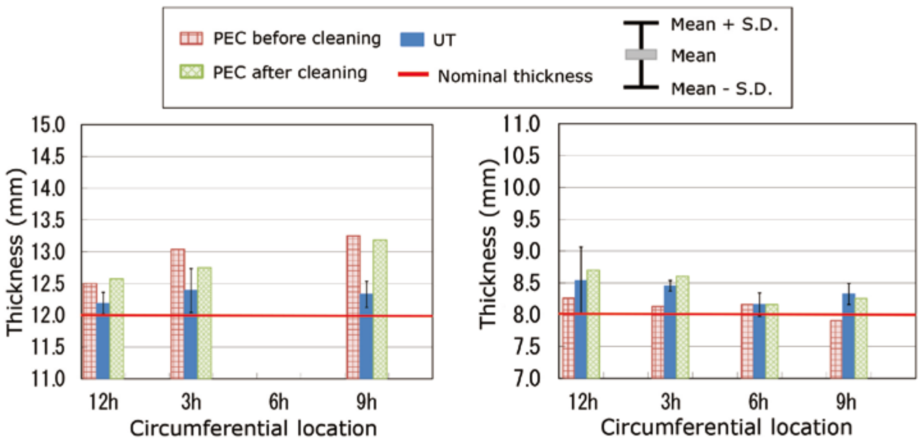


Fig. 2 Measured Thickness



thickness was measured by UT. Finally, PEC measurement was conducted again to examine the effect of surface preparation. Fig. 2 summarizes the measurement results at L.W.L−2.5 m of Pile A and at L.W.L.−1.25 m of Pile B. The horizontal axis of Fig. 2 shows circumferential locations in the cross-section of pile, and 12 h and 6 h correspond to the sea side and the land side, respectively.

The results show that the difference between PEC and UT measurements ranges from 1 to 8% of the thickness with an average of 5.5%, and that the effect of surface preparation on the PEC measurement is insignificant. Furthermore, the time required for the measurement was 15 to 20 min. per location for UT while it was only 15 to 30 sec. per location for PEC. These results indicate that thickness measurement by PEC has a potential to be used for the inspection of port steel structures.

Patch Plate Repair Design

One of the popular repair methods for corroded pipe piles is to weld a patch plate on the corrosion-damaged area, and in the typical design practice, a patch plate with a thickness equivalent to a thickness reduction is used. However, to recover seismic performance of the pipe pile to the initial level, a larger thickness may be required to recover the energy absorption capacity. In this study, finite element modeling for a steel pipe pile repaired by patch plates was developed, and pushover analyses of pipe piles with different structural parameters were carried out to examine the patch plate thickness required to provide the same energy absorption capacity based on the load-displacement curve as that of an intact pipe pile[3].

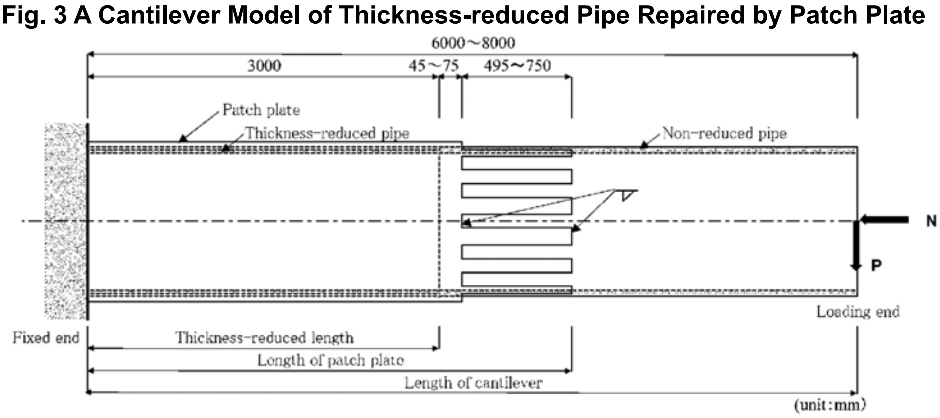
A pipe pile was modelled as a cantilever which is the top 60% of the whole pile. Fig. 3 shows the cantilever model extracted from the upper part of steel pipe pile. In the model, a thickness reduction was assumed to be uniform for the length of 3000 mm. The axial force, N, was applied first at the loading end, and the pushover analysis was carried out by gradually increasing horizontal displacement.

Pipe diameters used in the analysis are 600 mm, 700 mm, 800 mm, and 900 mm. Original thickness of steel pipe is either 12 mm or 16 mm. Thickness reductions are assumed to be 6 mm, 8 mm, and 10 mm. Cantilever lengths considered are 6000 mm, 7500 mm, and 8000 mm. Steel piles of both SKK490 and SKK400 are used. A ratio of the axial force to yielding axial force of an intact steel pipe, N/N_y, was considered in the analysis ranges from 0% to 20%. A total of 106 cases were analyzed.

Required thicknesses of patch plate from 106 cases are plotted in Fig. 4. In Fig. 4, the parameter of the horizontal axis was selected by referring to Ref. 4), where λ_p is a slenderness ratio parameter of thickness-reduced steel pipe pile, and R_{tp} is a radius thickness ratio parameter of the pile. The vertical axis is a parameter that represents a ratio of the patch plate thickness to the intact pipe thickness, where t_s, t_{p0}, σ_{ys}, σ_{y0} are patch plate thickness, intact pipe thickness, yield stress of patch plate, and yield stress of SKK490, respectively. A ratio of the required patch plate thickness to the thickness reduction was found to range from 1.0 to 1.4.

In Fig. 4, a trend curve of average values obtained by a nonlinear least square method is shown as a dashed line, and a solid line is an upper limit curve of the required patch plate thickness which is an average plus twice the standard deviation. The equation of the upper limit curve is also shown in Fig. 4. By using this empirical formula, a required patch plate thickness can be determined.

Fig. 3 A Cantilever Model of Thickness-reduced Pipe Repaired by Patch Plate



Summary

In order to achieve true life cycle management of port steel structures, the life cycle performance should be understood for the whole structure. Efficient inspection methods and effective repair methods discussed in this article will be able to contribute to better life cycle management techniques. ■

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Fig. 4 Required Patch Plate Thicknesses from 106 Analytical Cases