# Lifecycle Performance Assessment Technology for Port Steel Structures with a Focus on Post-repair Performance

*by Yoshito Itoh, Professor, Yasuo Kitane, Associate Professor, and Mikihito Hirohata, Assistant Professor; Civil Engineering, Graduate School of Engineering, Nagoya University*

### Prolongation of the Service Life of Aging Port/Harbor Steel Structures

In order to prolong the service life of aging port/harbor steel structures by means of rationalized maintenance, it is important to precisely gauge performance before and after repair, to assess lifecycle performance during the designed service life, and to provide appropriate inspection and maintenance. Targeting steel pipe piles with deteriorating performance due to corrosion, we have studied the post-repair load carrying capacity and durability of these piles repaired by steel plate welding. An outline of our study follows.

### Load Carrying Capacity of Steel Pipe Piles after Steel Plate Welding Repair

Fig. 1 shows the steel plate welding repair method[1]—a typical method used to repair and strengthen corroded steel pipe and sheet piles. In this method, the corrosion-damaged section is covered with steel patch plate, which is welded to the existing steel member using fillet welding. In cases when the corroded section is located in seawater, underwater wet welding is frequently adopted. Welding environments, dry or wet, can affect characteristic weld properties. It is reported that many weld defects occur during underwater welding and that whereas the hardness of welds in underwater welding increases when compared to that of open-air welding, ductility of underwater welds decreases[2]. Similar results were obtained from strength tests of fillet welds using steel pipe and steel sheet piles as the base metal[3]. As shown in Fig. 2, underwater fillet weld joints have larger static strength but much smaller ductility than open-air welds, and it was learned that these effects are more significant in sheet pile steel than in pipe pile steel.

**Fig. 1 Repaired Steel Pipe Pile**

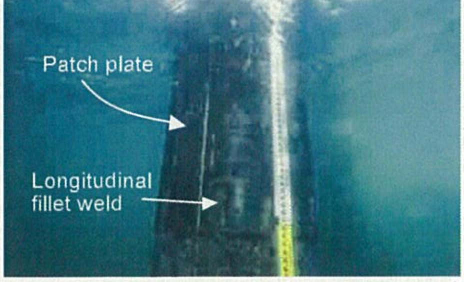
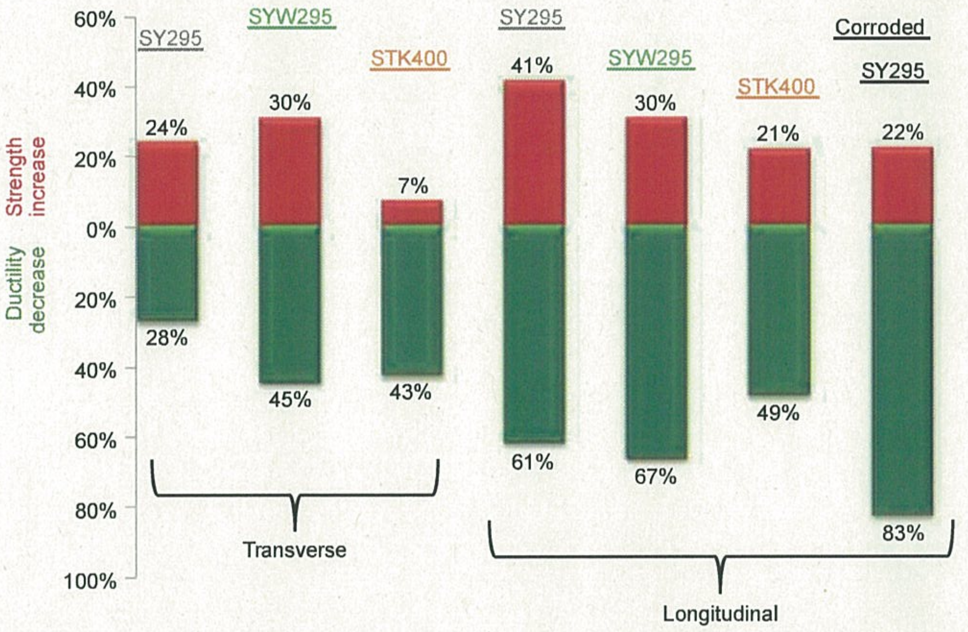



**Fig. 2 Relative Changes of Strength and Ductility from Open-air Welds to Underwater Welds**




Further, tests were conducted whereby steel plate welding repairs based on the current design method were applied to steel pipes whose wall thicknesses had been artificially reduced by cutting and whereby post-repair structural performance of the pipe was then examined by applying compression or flexural loading[4]. These tests clearly showed that, while stiffness and load carrying capacity of the repaired pipe against compression or flexural loading were recovered to nearly the same levels as before corrosion damage occurred, the corresponding ductility decreased from pre-corrosion levels. Fig. 3 shows the load-displacement curve obtained from the flexural loading tests.

As discussed above, the static strength of steel pipe after repair can be returned to pre-corrosion levels, but the repaired steel pipe will then be subjected to cyclic loading during earthquakes, and thus an important question arises as to whether or not the repaired steel pipe will be able to show appropriate energy absorbing capacity.

Fig. 4 shows the load-displacement curve of four kinds of steel pipes that were subjected to cyclic flexural loading in the nonlinear finite element analysis: (a) intact pipe (216.3 mm in outside diameter, 12.7 mm in wall thickness); (b) steel pipe having a wall thickness that was uniformly reduced by 6 mm in a 150 mm-long section; (c) steel pipe having a wall thickness that was uniformly reduced

Fig. 3 Load-Displacement Relationships of Steel Pipes under Flexural Loading

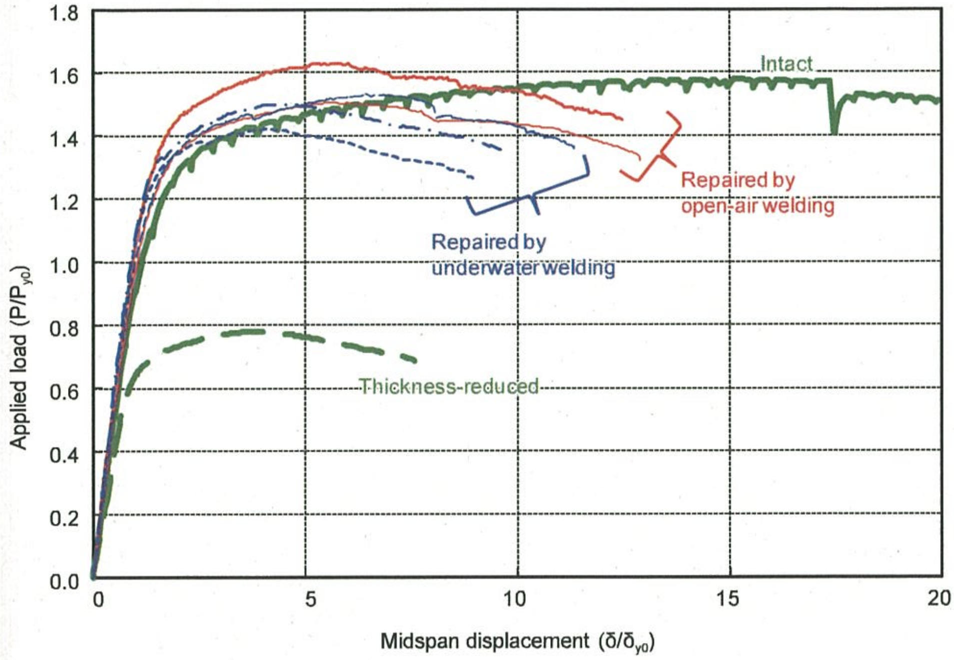
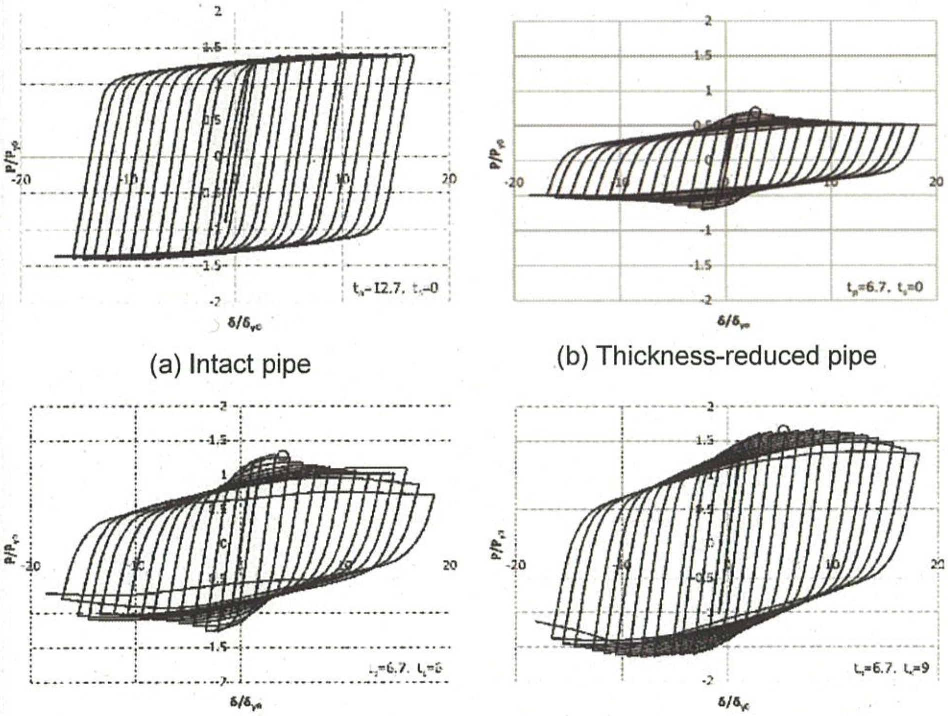



Fig. 4 Load-Displacement Curves of Steel Pipes under Cyclic Flexural Loading



(a) Intact pipe

(b) Thickness-reduced pipe

(c) Repaired pipe with a 6 mm thick patch plate

(d) Repaired pipe with a 9 mm thick patch plate

by 6 mm and was then weld-repaired using 6 mm-thick patch plate; and (d) steel pipe having a wall thickness that was uniformly reduced by 6 mm and was weld-repaired using 9 mm-thick patch plate.

It is found from the figure that, in order to return the energy-absorption capacity of corrosion damaged steel pipe to that of intact pipe, it is necessary to employ steel patch plate with a thickness greater than the reduction in wall thickness caused by corrosion[5].

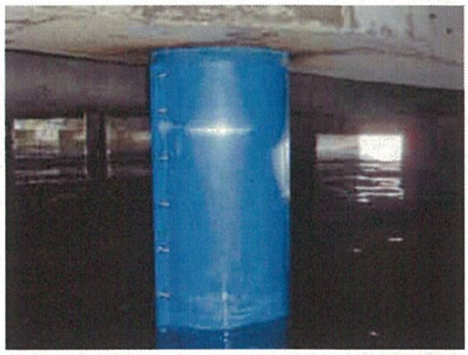


Photo 1 Steel pipe pile repaired by patch plates with petrolatum coating and FRP cover

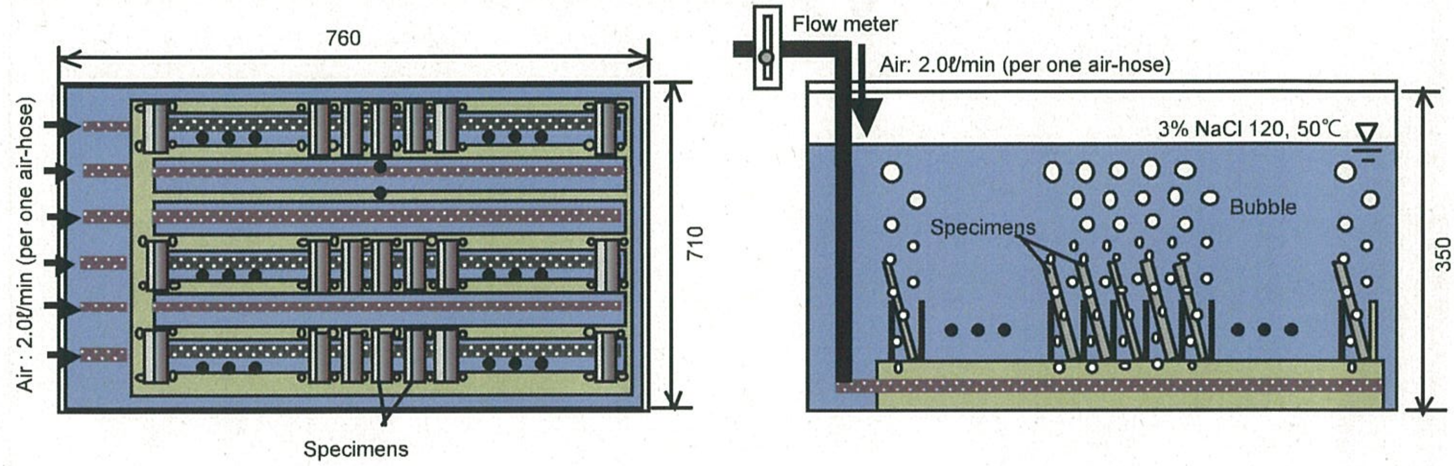
### Examination of the Corrosion Characteristics of Welds Using a Seawater Bubbling Test

In order to show lifecycle performance, it is necessary to understand post-repair corrosion resistance. In the current practice, corrosion-protection coatings are applied to steel pipe piles that have been repaired by means of steel patch plate welding. Photo 1 shows an example of such steel pipe piles to which petrolatum coating was applied and an FRP cover over the coating had been attached. It is accepted that such a corrosion protection is effective for about 20 years; however, in cases when an FRP cover has been damaged by floating objects and a part of petrolatum coating has been gouged away, the repaired section is once again exposed to the corrosive environment. While many research results are available that pertain to the corrosion characteristics of steel members in seawater, less research has been conducted that compares general sections of steel members with welded joints in order to demonstrate differences in corrosion characteristics.

Given this lack of data, we used a bubbling corrosion acceleration test (3% NaCl solution, 50°C, 28 days)[6] to examine the corrosion characteristics of steel weld joints. Fig. 5 shows an outline of the testing apparatus used in the test. Two kinds of base plate were used for the test specimens, SY295 and SYW295, while SM490 steel plate was used for the patch plates. The patch plates and base plates were weld-joined by means of fillet welding using E4319 welding electrodes.

In the test, pre-test and post-test surface profiles were measured and compared using a laser displacement sensor to determine corrosion loss in the welds. Fig. 6 shows the corrosion loss in the weld of one specimen. As seen in the figure, the fillet weld joint shows uniform corrosion, and lacks any locally severe corrosion generated by uneven sections in the weld bead surface or by welding toes.

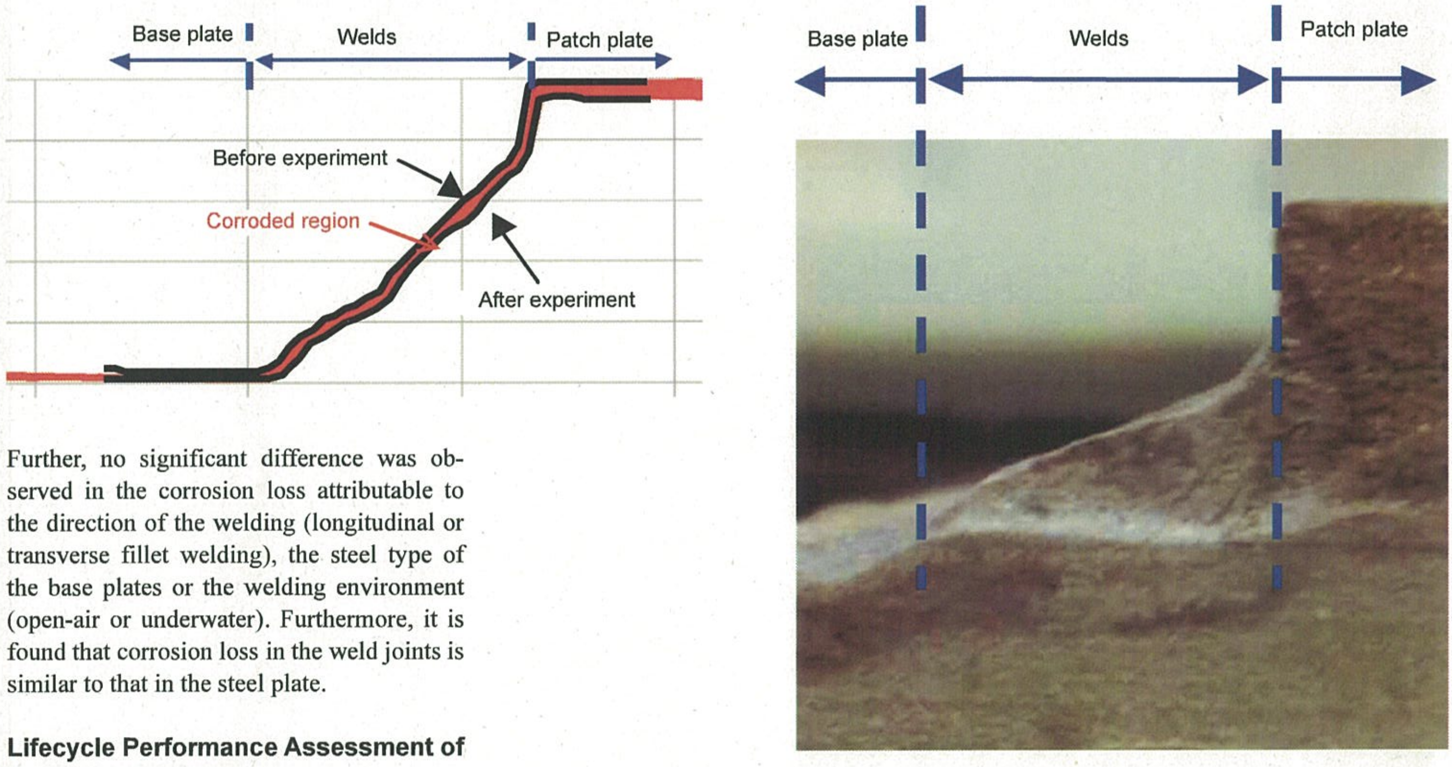
**Fig. 5 Accelerated Exposure Test System for Underwater Corrosion**




(a) Plan view

(b) Side view

**Fig. 6 Change of Surface Profile of Weld due to Corrosion**




Further, no significant difference was observed in the corrosion loss attributable to the direction of the welding (longitudinal or transverse fillet welding), the steel type of the base plates or the welding environment (open-air or underwater). Furthermore, it is found that corrosion loss in the weld joints is similar to that in the steel plate.

### Lifecycle Performance Assessment of Port Steel Structures

With the goal of improving the lifecycle management of port/harbor steel structures, we examined the load carrying capacity of corrosion damaged steel pipe piles that had been repaired by means of steel plate welding in order to better understand the lifecycle performance of steel pipe piles. Our future goal is to assess the post-repair load carrying capacity of entire pier/quay structures in addition to single steel pipe piles. ■

### *References*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