Development and Application of Dry Process Caisson for Maintenance of Submerged Harbor Structure

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Abstract

Together with the trend of enhancement in domestic industrial development and economic progress due to import and export, the demand for construction of the roads, bridges, especially port facilities, and several coastal protection and ocean structures is increasing rapidly. MOMAF of Korean Government is driving construction of 9 new ports and renovation of the existing fishery ports. Among these structures most of bridge base, wharves, dolphins, quays, and jetties are being newly built of steel or concrete pile. As the base, supporting bulkheads, and piles are underwater after construction, it is difficult to figure out the status of structures and not enough to get maintenance and strengthen the structures. Every year, moreover, these works suck the government budget due to higher incomplete maintenance expense for protection from corrosions of structures and increased underwater construction period. For the purpose of cutting down the government budget, it is necessary to extend the life cycle of the existing structures. We developed a new method for maintenance of submerged structures near the waterline by allowing dry work environment with the floating caisson. The method shows easy to move around the working area and handle. It also showed not only a significant reduction of maintenance expenses and time for anti-corrosion work but also better protection. This will be a milestone to reduce the maintenance and construction expenses for the shore and water structures.

Key words: Submerged structure, Dry process, Steel pile, Floating caisson, Corrosion and Anti-corrosion

1. Introduction

1.1 Background of Study

Recently, together with the trend of enhancement in domestic industrial development and economic progress due to import and export, the demand for construction of the roads, bridges, port facilities, several coastal protection, and ocean structures is increasing rapidly. Especially, port facilities, which take in charge of main role of ocean shipping together with land transportation facilities such as road, railway, etc., are being constructed newly in the form of piers, dolphins, wharves, jetties, and landing stages, etc. adopting ferroconcrete, steel pipe, PC concrete, with the help of Korean government policy of 9 new ports and renovation of the existing fishery ports. As is well known in the construction industry, these support members and the base are subject to damage due to corrosion, erosion, collisions, etc. and are likely to require repair and/or replacement from time to time. It is especially true of those portions of the support members which extend through the splash zone which experiences the forces generated by the action of the waves. As the extension of durability for existing port facilities is expected to be very important in curtailment expenditure of national finance, these are being repaired and maintained with high costs and for long construction periods adopting iron plate molding and concrete work under water every year but is not reached at the satisfying level yet.

Moreover, most of seawalls, supporting bulkheads and piles are located at the waterline or under the sea surface after construction, it is difficult to figure out the status of structures and not enough to get maintenance and strengthen the structures. Also, as it is necessary to stop leaking considering structure durability but it needs high cost caissons and complex installations at the field which accompany divers for repair and reinforcement works, there exist a lot of obstructions and bottlenecks in construction quality control. The repair of these elements, especially in the splash zone, have proven costly due to the specially trained personnel including highly trained divers and the excessive time normally required to perform the work.

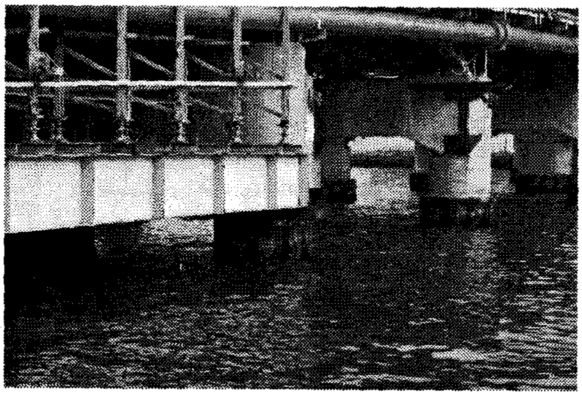

Fig. 1 Tidal zone of concrete pile and bridge base

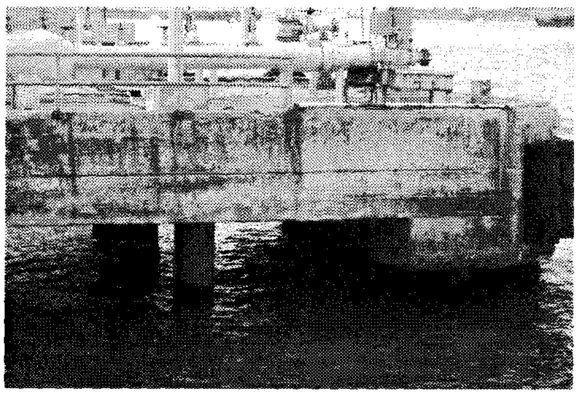

Fig. 2 Wave splash zone of jetty

Fig.1 and Fig.2 show examples of corrosion progression at the existing bridge base and jetty for splash zone which needs maintenance repair. When the water leakage from the submerged caisson happens at the step of maintenance work, it drives to the problem of water pollution, earlier corrosion to concrete, and oxidation of steel etc. as well as in qualitative level and delay of construction. Fig.3 is displaying the typical pattern of corrosion rate on the flanks of the steel piles. Splash zone of ± 1.5m section of low water level shows that the corrosion is worst. The right side of Fig.3 comes from the field investigation at northern part of Dutch coast (Wijngaard, 1980). The residual material thickness was measured by an ultrasonic thickness gauge. The estimated maximum corrosion rates that were found for the distinguished piling zones are: i) atmospheric zone 0.05~0.07mm/yr, ii) splash and tidal zone 0.12~0.27mm/yr, iii) submerged zone 0.026~0.09 mm/yr, and iv) subsoil zone about 0.015mm/yr. These values agree well with results from other places in Europe and Far East

Asia as recorded in literature. Low water and splash zone of steel piles are susceptible to severe corrosion. When concentrated corrosion starts, soon or later, at an unpredictable point in time, it progresses at a very high intensity. The present study provides a reusable, watertight working caisson which is open at the top to the atmosphere and which can easily be installed and removed in the splash zone around a support member of a marine structure.

1.2 Necessity of Dry Caisson Method

Most metals exist by ore composite of oxide or sulfide etc. in natural conditions, and are refined by reduction process applying a lot of energies here. Therefore, it is in unstable state in natural conditions, metal has an instinct that it returns to the stable state bonding by oxide ore. Because of this, it forms sometimes rust or disappears by corrosion extension. Corrosion is progressing slowly in hull, machine, boiler, marine structure, underground structure, firefighting device, coolant system of nuclear power plant etc. and 10 ~ 20% of iron production is consumed by corrosion or decay. It is known that the economical damage reaches to 2 ~ 3% of GNP in advanced industrial countries as shown in Table 1 (Port Technology International, 1988).

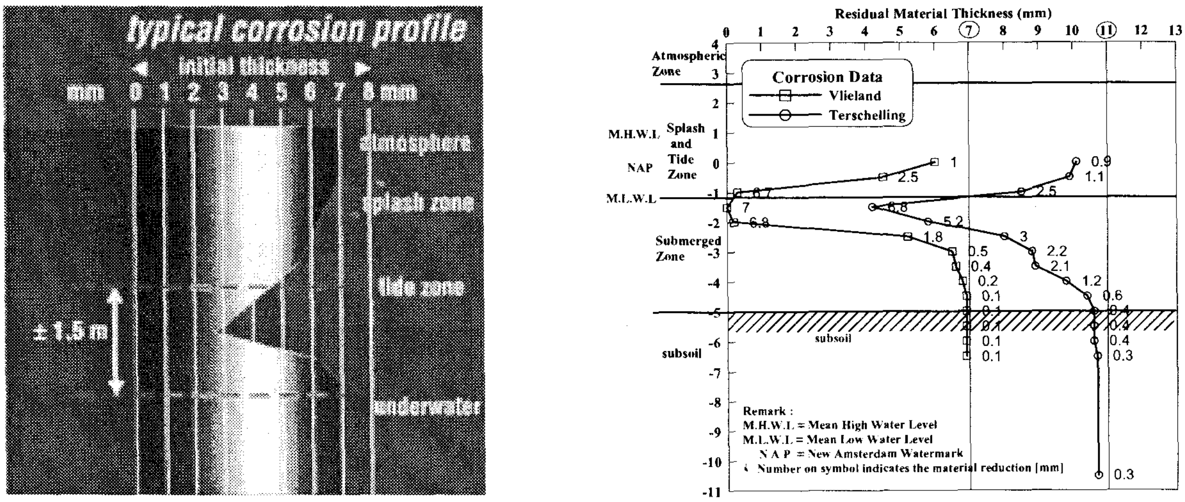

Fig. 3 Typical pattern of corroded area of steel pile and field survey corrosion data

The total lifetime of steel piling constructions in seawater depends mainly on the corrosion rate just below or near the low tide line. The corrosion proceeds principally from the water side of the piles. Maritime as well as construction steel are in general protected against corrosion and the protective systems are necessary.

Many considerations have been taken into account for not adequately protecting steel piles, like the belief that steel does not rust under water, that a steel plate as thick as the wall can't be destroyed by exposure to water or that pre-coating the piles is the same as protecting the piling in situ. Bituminous coating are often applied, to protect the steel piles against the chemical and/or biological action of the seawater, but such coatings can only be applied on the region above the low water line for existing structures. However, as the anti-corrosion coating and the anti-biological fouling application are not study area at this moment, we emphasize on the design of dry working process caisson for repairing the support members of marine structures which have deteriorated near the waterline.

Table 1 Annual corrosion loss of major countries (for GNP $8,000 and population 40,000,000)				
Name of country	**Year**	**Damaged Expense ($/yr)**	**Rate of GNP (%)**	**Saved Expenses ($/yr)**
U.S.A	1998	39 trillion	5.0	9.8 trillion
JAPAN	1997	2 trillion	1.8	0.5 trillion
U.K	1969	0.4 trillion	3.5	0.1 trillion
GERMANY	1969	0.8 trillion	3.0	0.2 trillion
RUSSIA	1969	0.87 trillion	2.0	0.22 trillion
AUSTRAILIA	1973	7 billion	1.0	1.78 billion
KOREA	1999	0.7 trillion	1.8	0.19 trillion

For the last decades, a cathodic protection has been put forward as an effective means for the protection of steel structures in seawater, but the effectiveness at the splash zone is doubtable and as a consequence of the expenses connected with the application, its use has been limited to expensive offshore construction like offshore drilling industry, till now (Korean Research Institute of Anti-Corrosion, 2003).

2. Analysis of Technical Background and Application

2.1 Necessity of Dry Environment and Anti-corrosion Process

The corrosion rate of sea environment is believed that it is fast than 10 times of land based environment. Moreover, the method for anti-corrosive treatment at the splash zone has a certain limit. Not only it brings sea pollution through the use of hydraulic paint, but repair works under the water bring qualitative difference that is much relied on worker's state.

There are 4 main methods for protection marine structure against corrosion such as land painting, electric anticorrosion, underwater taping, and hydraulic painting. Table 2 is comparing with each case in terms of usage, construction and workability including merit and demerit of each method. Among these the most superior one is land based coating method but it gives a serious problem at piling process. The painted pile in land does effective for protection from the intrusion of corrosion, but when those are moved to the target section of pile installation, crack occurs at the pile injection and anti-corrosion processing becomes incomplete.

In repair work it is difficult to handle a lot of landing stages in a short period and, therefore, the amount of work done in a day is limited as well. For this reason, the tape method by divers is fallen into declination and the taped parts are being attacked by wave force which might reduce the adhesive strength of tape, because the seawater aggravates corrosion easier by permeating to the internal furnace. Hydraulic painting under the water might bring another problem of chemical dissolution in the marine ecology system during coating and scratching work.

Therefore, we concluded that anti-corrosive treatment under the dry environment after injection of pile is the most effective method for perfect corrosion protection at the splash zone. From this analysis a working condition of dry environment is necessary and this guided the direction of this research. Precaution made to a working space for enabling repairs, corrosion protection, inspection, maintenance and other work operations to be carried out, from the splash zone and downwards to a maximum practical depth, on quays and harbour installations, pipelines and offshore structures, etc.

Table 2 Comparison of anti-corrosion methods

Division	① Existing paint method	② Electric method	③ Tape method	④ Hydraulic paint method
Main usage	•Costal mooring facilities	•Costal mooring facilities	•Steel pile at splash zone & tidal zone	•Underwater repair & reinforcement
Construction & workability	•All section by land work (polyethylene clothing) •Difficulty in underwater work •Unable underwater repair & reinforcement	•High cost of early construction	•Mainly underwater work • Difficulty in partial maintenance	•Divers work for painting •Difficulty in long term work •Construction period is prolonged due to repeating application
Advantage	•Satisfactory waterproof from seawater • Satisfactory corrosion Protection effect	•Satisfactory corrosion Protection effect on underwater section	•Possible underwater work •Satisfactory corrosion Protection effect	•Possible underwater work
Disadvantage	•1st painting application thickness is around 100μm •Difficulty in underwater work •Damage to the applied paint during piling work process	•High construction cost •Low performance of anti-corrosion work in the air •Persistent maintenance need	•Need cover for corrosion prevention tape application •High construction cost •Prohibition of survey after underwater taping work •Difficulty of waterproof on painting surface	•Expensive coating material use •High construction fee by excess damage rate of material •Irregularity on coating thickness •Worry on crack of coated surface

Table 3 Comparison of existing dry maintenance and strengthen methods

Division	① Temporary wall	② Sheet Pile	③ DZI	④ Dry Caisson Existed
Main usage	•Repair & reinforcement with concrete well foundation	•Repair & reinforcement with concrete well foundation	•Repair & reinforcement with costal sheet pile	•Repair & reinforcement with coastal steel pile
Construction & workability	•Difficulty in construction and workability	•Difficulty in construction and workability	•Simple construction and workability	•Partial improvement of construction and workability
Advantage	•Work process simplicity	•Stability secured	•Simple installation of equipment	•Dry working condition
Disadvantage	•High construction cost •Pollution possibility •Danger of wall collapse	•High construction cost •Removal cost addition burden	•High construction cost •Limited to sheet pile	•Time consuming in construction equipment setup and transfer (chain block use)

2.2 Existing Dry Processing Method

Maintenance and repair work at the waterline is usually quite difficult because of wave action and because it is necessary to perform repair operations at a substantial distance below the waterline. It is desirable to carry on maintenance and repair operations in a watertight caisson attachable to the leg of a marine structure from which water can be removed and excluded so as to provide a space extending a substantial distance below the waterline within which workmen can move freely. A number of structures have been devised for this purpose, none of which are entirely satisfactory for one reason or another (Castellanos, 1962; Hellmers, 1976; Wallevik, 1982; Tate, 1991). Temporary wall and sheet pile method are applied in a large scale of construction object but do not fit for small or pier type structures. Dry setting installation method, so called DZI method, is for sheet file repair work. DZI has submersible cofferdam which is attached to the sheet pile bulkhead. However, heavy crane should hold the DZI system throughout the whole working process. More recently, a dry caisson or cofferdam (Thoresen, 1988) has been proposed to support a form on the single straight pile, but there were extra crane and chain block attachment work to hold steel pile and to move to the other pile. We considered that the time required on installation and actual work would be strongly linked with the economic performance.

Table 3 compares each case in terms of usage, construction and workability including merit and demerit of each method. From this it is expected that a self floating dry caisson will bring a great effect in expense and time.

3. Development of Dry Processing Caisson (DPC)

3.1 Brief Description of the Design

According to one feature of the design, there is provided a chamber for the working space at the center circle having 6 ballast compartments outer boundary of it, which will give self floating ability. In this way it is easy to detach from the marine structures and move away in emergency case such as typhoon prevailing, etc. Stability of the caisson in the seawater could be adjusted with ballast/discharge pump unit attached to each sector. In the form of the design illustrated in Fig.4 to Fig.5, it is assumed that the top of the pile is covered by the structure slab and therefore, it is difficult to access with outer repair and/or maintenance system. As water is removed at the working chamber, buoyancy urges the system upwardly and thereby the 4 hydraulic jack suspensions reach to the slab of the marine structure in order to keep the system stable condition horizontally. And also the water pressure from the side of the system and the watertight gaskets will establish and maintain the seal. The gaskets will respectively engage each other when the sections are closed to give an effective watertight seal between the flanges. Although there is seawater leaking at the gap of pile and watertight rubber, the water which is trapped and the leaks within the working chamber will be removed by hydraulic pump attached.

The working space consists of two chamber halves which are hinged together at one longitudinal edge there of. The two halves of the chamber can be locked together in contact against each other by 2 hydraulic jack units at the bottom of the system. One unit is for closing the caisson and another is for locking tightly the other half around the steel pile. The stiffening struts (space maintainer in Fig. 5) are provided at the middle of the working chamber about 90 degrees interval. Under the impact of waves and vibrations, the struts in this position will form a very effective supporting against the walls of the chamber. Fig.6 indicates the plan view of the system and the hydraulic units which will grasp the pile tightly.

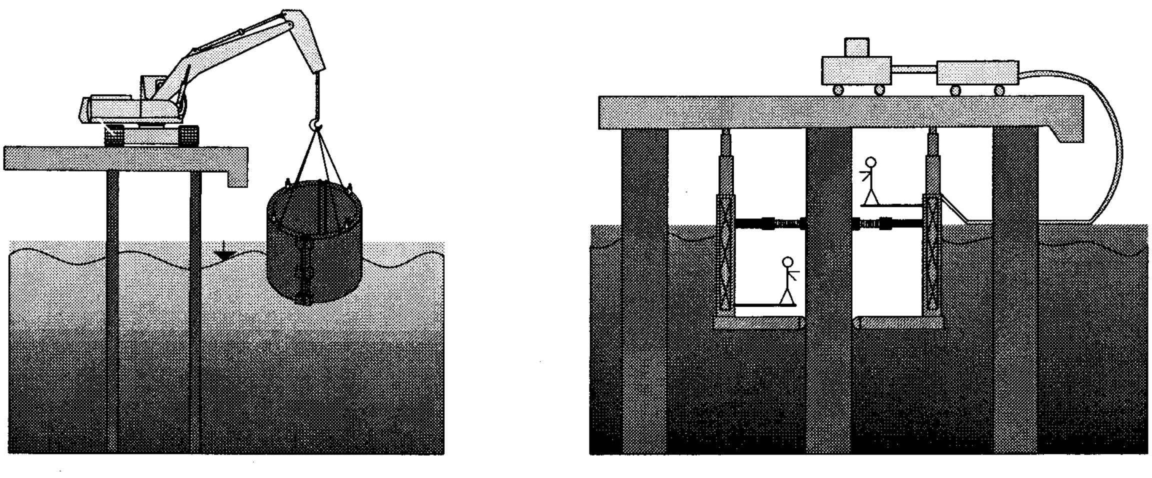

Fig.4 Schematic diagram for maintenance work with DPCM

3.2 Model Experiment and Application of DPC

First, we made a pilot experiment using an acryl hydraulic model. The pilot experiment includes self floating test, stability test, and holding structure and discharging test. Before the test, we had designed 1/6 scale model with the calculation of buoyancy and gravity forces, and total water pressures. The designed model was moved to the rectangular water tank. Fig.7 and Fig.8 are showing the status of experiment. We found that the system worked well as we had calculated. However, it is necessary to adjust the water levels of the sector ballast tanks for stability of the model when the working chamber is in an open state.

Fig.9 and Fig.10 show the field test of the real caisson at the pier construction site of a ship yard in Busan city in terms of self floating and holding capabilities including discharging water test inside the working chamber. Although the specific weight of acryl 1.19 at the model is quite different with 7.85 of the steel plate at the real caisson, the buoyancy force of the real scale caisson was enough to set the working equipments and personnel on the caisson. Fig.11 through Fig.16 are showing the real field application of DPC at the tanker terminal pier. The procedure includes floating, moving, installation, pumping, repairing, and coating.

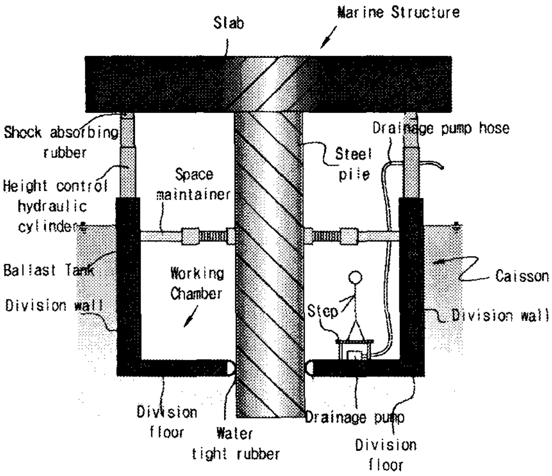

Fig.5 Section view of DPC

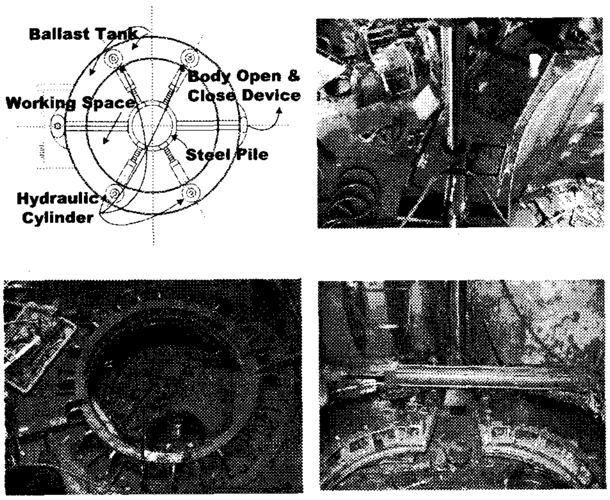

Fig.6 Plan view and components of DPC

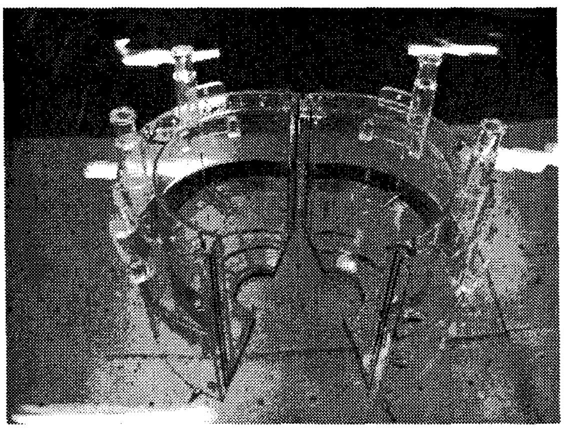

Fig.7 Floating test of DPC Model

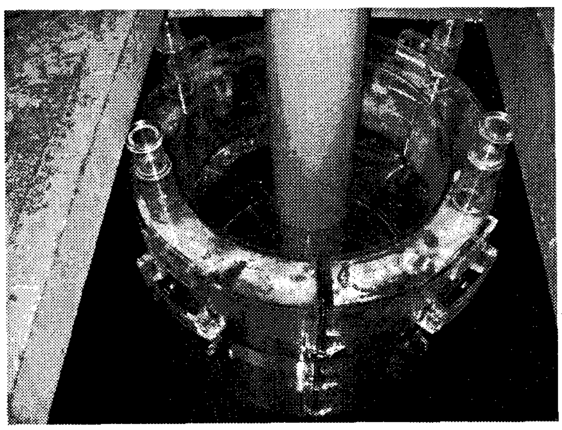

Fig.8 Holding test of DPC Model

For repair of a column of pile, the caisson was lowered down and floated on the sea surface. This was moved to the pile under the pier slab with a small boat. After that, the caisson was opened with the hydraulic unit and fastened tightly to the pile as shown in Fig.12 and Fig.13. The caisson is then pumped empty for preparation of the repair work. The installation procedure took 30 minutes, which could be reduced from the repeated working.

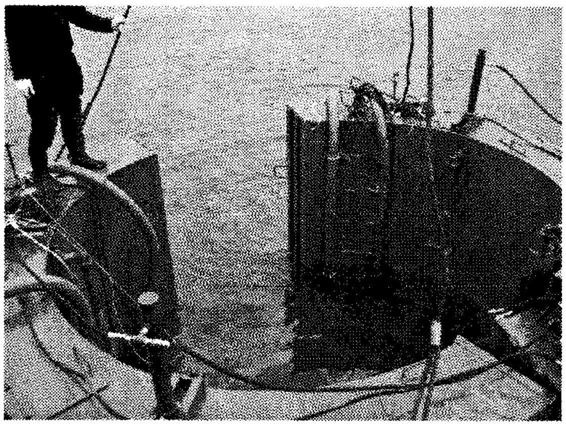

Fig.9 Floating test of the field module

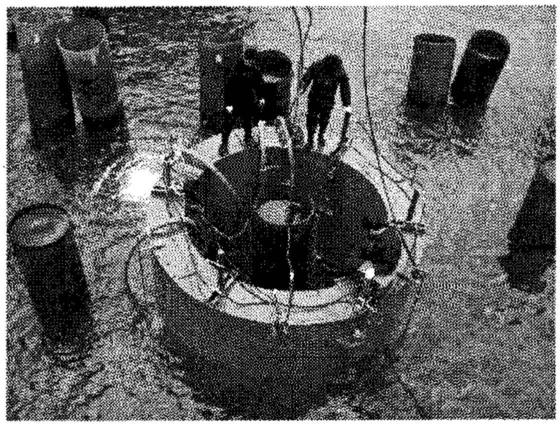

Fig.10 Holding test of the field module

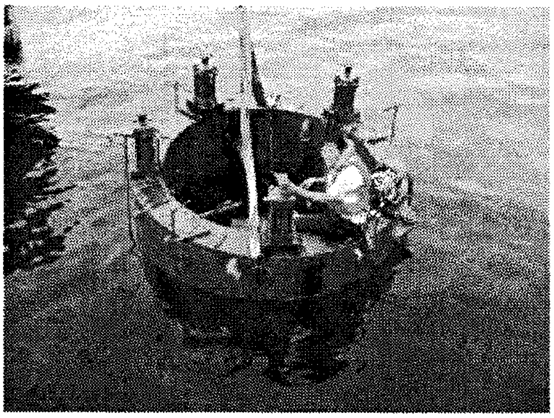

Fig.11 DPC floating

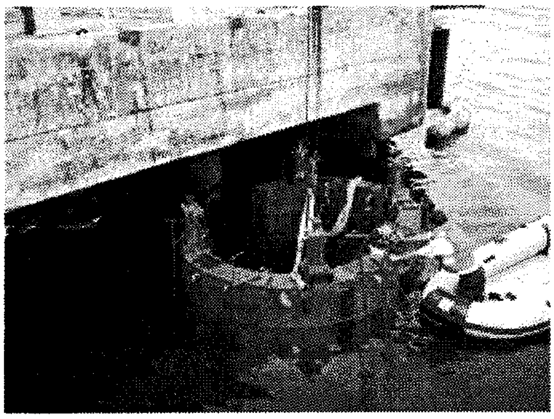

Fig.12 DPC moving

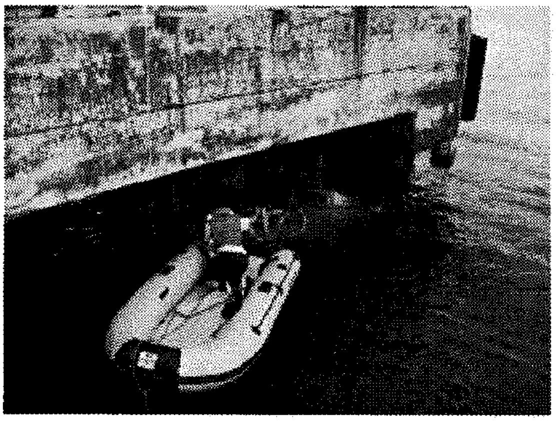

Fig.13 DPC installation

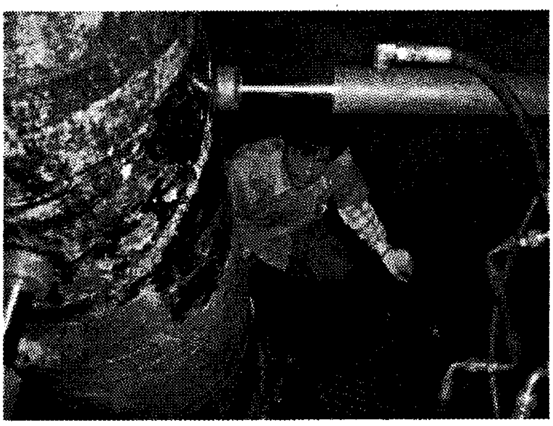

Fig.14 Exposed working chamber

When the pile surface has been carefully chiseled, and waterjetted or sand ballasted, the reinforcement, if required, is put in place until the column of the pile has regained its cross-sectional dimensions. The final step for the repair work was coating with anti-corrosion pain as in Fig.16.

Repair work does slowdown the corrosion rate depending on the efficiency of marine work chosen. Research report (Ministry of Construction & Transportation, 1998) describes that the expense due to corrosion can be reduced up to 25% of total cost. The method proposed here in this study might contribute to reduce this corrosion loss. The design is practical to repair piers, dolphins, jetties, bridges, and marina facilities, etc., especially in pile structures with narrow intervals.

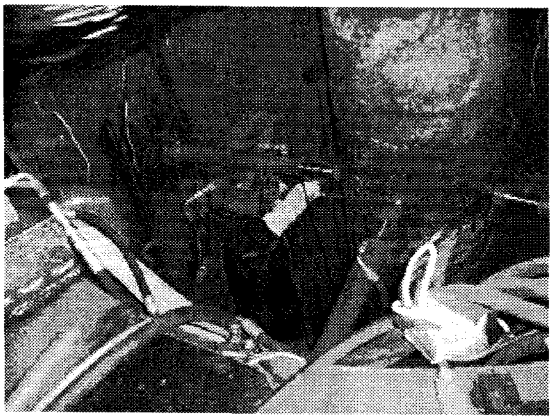

Fig.15 Water jet and sand blasting to the steel pile

Fig.16 Dry coating on the clean steel pile

4. Conclusions

An object of this study is to provide dry working space to the construction workers with a marine caisson which can be attached to the steel piling and partly submerged so that the affected area of the piling can be reached and worked at dry condition. We hoped to develop a marine equipment which might contribute to extend the lifecycle of the submerged steel pile structure and are also sure that it will work well on the corrosion protection in the long term basis. We adopted self floating structure considering mobility and easier detachment from the marine piles in emergency case, as well as supplying a dry working environment. Before the real scale module, we had designed a 1/6 scale acryl model with the calculation of buoyancy and gravity forces, and total water pressures, and made a test for floating, holding, and water removing tests. We made a dry environment experiment first with a designed floating caisson which had attached to the marine pile structures. Thereafter, we applied the design to the real terminal successfully.

When confronted with a deteriorated marine structure, one often tends to choose a method of repair that involves the lowest cost at the moment, without considering the lifetime of the structure. Unfortunately, this will usually imply repeated repairs and is an altogether wasteful solution. Irrespective of the marine structure to be repaired is new, or 40-50 years old, in both cases the cost of repair and the assumed remaining life of the structure should be considered as a whole. In connection with repairs on old marine structure, the surface of the structure should be cleaned and coated to get a good adhesion all over with the right anti-corrosion paint.

The environmental problem, as we see in a current point of time, becomes serious day by day and the marine pollution by the marine repair and/or reinforcement work is not out of this boundary. Removal of repair construction waste in this case is available without giving pollution load to the marine environment. This also will be recognized as an environmental-friendly technology minimizing eco-problem.

The DPC is a perfect solution for checking the status of the marine structure or maintenance problem that accessibility has been difficult, specially problems of oxidation and water pollution by concrete in water, heavy weight of iron plate mold, and difficulty in underwater welding, etc. The DPC is a semi-permanent structure and the approach by DPC might provide a good quality of working environment and a promising result at the marine construction industry in future. It seems, therefore, for the time being, that the floating dry caisson method is convincing the quality of repair work and would be the most cost effective tool at the same time.

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