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Application Research on Corrosion Protection of Mega-Float by Titanium Clad Steel Lining



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Abstract

Mega-Float is a ultra large floating structure, whose size can be several kilometers scale and planned to be used for city infrastructures, such as the airport, the heliport and the power plant, etc. and then expected to have ultra long durability over 100 years. Mega-Float Research Union was established in 1995 for the realization and the research project is now going to overcome some difficulties. In this project, titanium clad steel lining was adopted as the corrosion protection method for the splash zone of the around side wall, considering ultra long durability. Various techniques for the lining work, such as automatic titanium welder and the repair method for some type of damages of titanium clad steel lining, were developed and tested using the proto-type large-scale floating model (300m length, 60m width, and 2.0m height) which was constructed in a real sea area. It was, from these results, confirmed that the titanium clad steel lining was a very useful corrosion protection method for Mega-Float.

1. Introduction

Japan is surrounded by sea and its main economic and industrial centers are located in coastal areas. A very large proportion of its social infrastructure, including communication systems, transport systems, and public buildings, is also situated in coastal areas, but because of the limited amount of land space available, planners hope to locate such facilities offshore in the future. The utilization of floating structures is thus attracting the attention of developers. The sea is quite deep in some of the offshore areas being considered, but such areas can be effectively utilized by employing large-scale floating bodies, as shown in **Fig. 1**. Floating structures of this type can be put into service in waters of any depth and will not harm the environment. Since the component units of the floating body can be manufactured separately at facilities on land and then be assembled on the service site, the construction time is significantly reduced. In addition, offshore floating structures of this kind are not likely to be damaged by earthquakes.

In April 1995, the Mega-Float Technological Research Association was established mainly by the shipbuilding and steel industries

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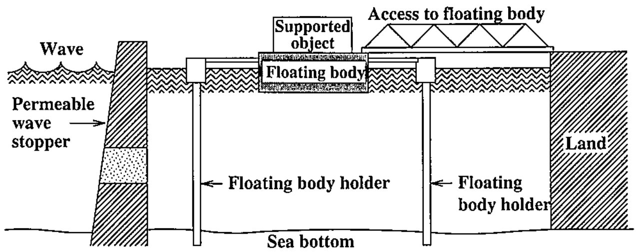


Fig. 1 Schematic of mega-float body

to develop such floating structures. The Association has conducted studies on "Mega-float structures several kilometers in size and having 100-year durability". In Development Phase I from 1995 to 1997, theoretical researches on the design of floating structures, experimental manufacturing of various parts and elements, and assembling of the components of a floating structure in an actual sea area were conducted. As a result, a prototype floating body having a size of 300 m (length) × 60 m (width) × 2.0 m (height) was constructed for verification tests. The development goals listed below were specified in this phase[1-4].

(1) To develop technologies for designing and analyzing large-scale floating bodies with a depth/length ratio of about 1:1,000
(2) To develop on-site technology for assembling floating bodies with an area of 500 ha
(3) To develop protective technology to guarantee 100-year durability
(4) To develop on-float infrastructures with functional capabilities comparable with those of on-land counterparts
(5) To evaluate the effect of the mega-float structure on ocean currents and marine biological systems

In Development Phase II from 1998 to 2000, objectives (2) and (4) above were continuously studied and a large prototype floating body of 1,000 m × 60 m × 3 m was constructed, followed by landing and take-off tests on the floating body using airplanes.

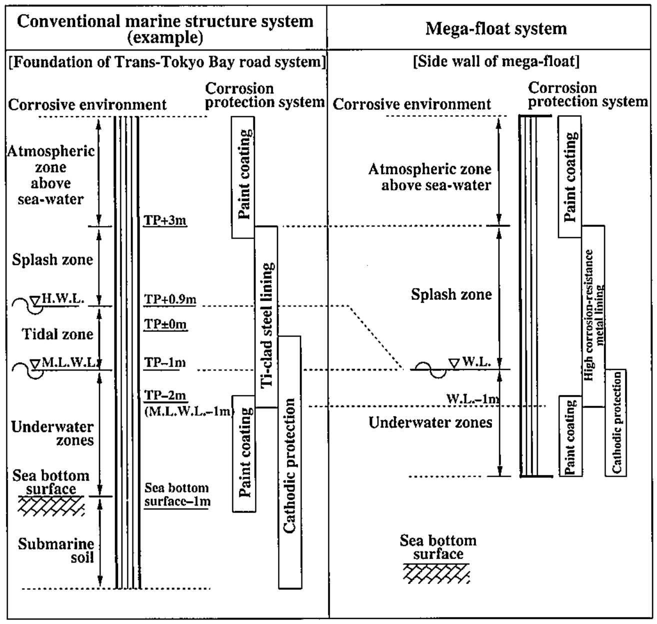
We investigated several matters pertaining to goal (3) in Development Phase I: specifications for a corrosion-protection system that would provide 100-year durability, the use of corrosion-resistant metal to protect the structure's splash zone, a method of monitoring the long-term maintenance and management of the floating body, and in-water repair operations. Because the study was only three years long, we did not experimentally test the durability of the candidate materials, and instead evaluated them based on a survey of the literature. The only method of corrosion protection studied experimentally was the application of corrosion-resistant metals to the floating body.

Within this framework, we focused on the suitability of Ti-clad steel. Our findings are summarized in the discussion that follows.

2. Corrosion protection systems applicable to the side and bottom surfaces of floating structures

Table 1 shows the corrosion protection system for floating structures proposed by the Mega-Float Technological Research Association compared with a conventional corrosion protection system employed in a marine structure (Trans-Tokyo Bay). The corrosion protection system for floating structures was designed with the specifications to provide 100-year durability, as it would be impossible to perform maintenance work on the floating structure in a dry dock once it was completed on-site and that the floating structure itself would serve as an important infrastructure[5]. For example, easy-to-

Table 1 Corrosion protection systems for a mega-float and a conventional marine structure



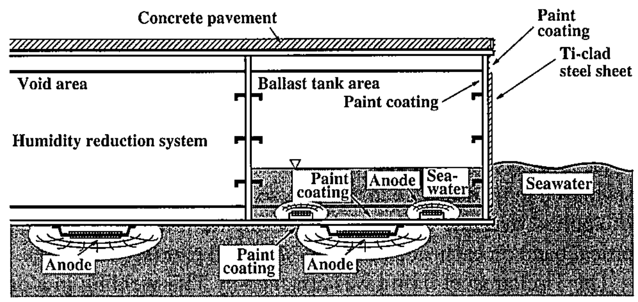


Fig. 2 Corrosion protection system for mega-float body (100-year durability)

maintain coating was applied to the surfaces exposed to the atmosphere above sea-level, maintenance-free type corrosion-resistant metal lining was applied to the splash zone, and cathodic protection technology which features excellent cost performance and reliability was used as the base coating of the underwater zones. The zones in relation with coating above are defined below.

(1) Atmospheric zone means sections above the splash zone.
(2) The upper limit of the splash zone is the mean high-water level (H.W.L.) plus half the wave height approximately. The wave height is determined on the basis of the peculiarities of the waves on the site and the in-service length of the structure. The lower limit of the splash zone is the seawater level (W.L.) of the floating structure on the basis of the theory that cathodic protection systems are effective in protecting a conventional marine steel structure below the mean low-water level (M.L.W.L.).
(3) The upper limit of corrosion-resistant metal coating is equivalent to the upper limit of the splash zone, making reasonable allowance for actual application conditions with respect to the edges joining different metals. The lower limit, on the other hand, is the W.L. minus 1 m for preventing intensified corrosion at levels immediately below the W.L.

Fig. 2 shows the corrosion protection system specifications for mega-float.

3. Outline of program for testing Ti-clad steel sheet lining

In the verification test, nine 100 × 20 m floating components that had been manufactured at facilities onshore were welded together at sea to make a single 300 × 60 m floating body. The height of this structure was 2 m above sea level. The large service structure currently planned will be 5 m above sea level and 5,000 m long. The verification test of the Ti-clad steel lining, conducted between 1995 and 1997, focused on three issues. The first was whether the lining could be applied to the structure while afloat at the construction site, the second was the development of an automated welder, and the third was the development of an on-site repair procedure.

4. Verification of applicability of lining at service site

As reported earlier[6-7], the splash and tidal zones of the bridges in the Trans-Tokyo Bay (TTB) road system were protected against corrosion by Ti-clad steel sheet linings. These were applied in the factory by the manufacturer and not on the construction site. For the mega-float structure, however, the Ti-clad steel sheet (thickness 5 mm: 1 mm Ti, 4 mm steel) will be applied to the side-wall splash zone at the construction site at-sea (see **Figs. 3 and 4** for the configuration). Since there was no established technology for this, several problems had to be solved:

(1) How to cope with irregular vibrations caused by wave impacts
(2) How to operate in a narrow dry chamber
(3) The feasibility of welding a 2-m high vertical structure (in the future, it would be 5 m)

A suitable lining-weld technology had already been developed for the TTB system, and the corrosion resistance of Ti has been well established in field service in the past, so in our study, the lining was not applied over the entire surface of the hull, but only to a 2-m vertical band on each side of the on-site weld part (see **Photo 1**).

The Ti-clad steel lining was attached by TIG welding in a dry side-chamber environment (**Photo 2**). The side chamber was also used for welding components of the floating structure prior to the application of the lining and for touching up the paint coating on the underwater surfaces after attaching the lining. **Photo 3** shows how the lining was applied in the dry side chamber, and **Photo 4** the appearance of the applied Ti-clad steel sheet.

Test welding of the Ti-clad steel sheet was done in October 1995 in calm water in a dry dock and in July 1996 at the test area of the floating structure. Weather conditions at the site were poor during the July 1996 test, with considerable wind, rain and waves, but the chamber did not move significantly because it was fixed to large, heavy floating components, and as a result, the welding operation was completed without serious difficulty. The welded parts passed

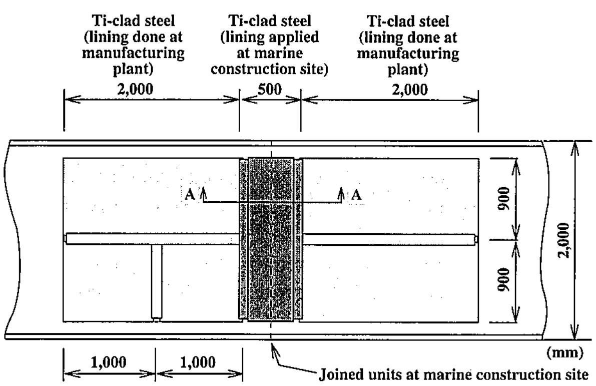


Fig. 3 Ti-clad steel sheet lining for marine structure

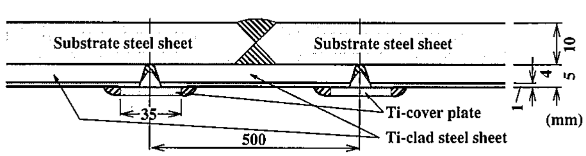


Fig. 4 Cross-section of Ti-clad steel lining (along A-A in Fig. 3)

Photo 1 Ti-clad steel lining in the factory

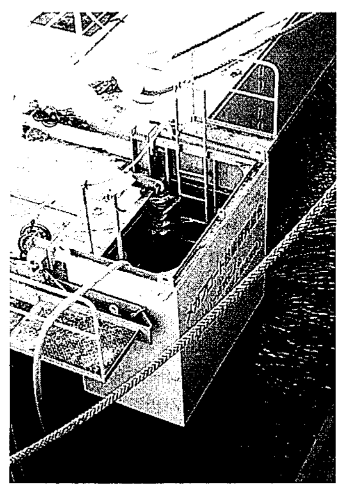


Photo 2 Attached side chamber

Photo 3 Applying the lining in the chamber

Photo 4 Ti-clad steel lining done at the marine construction site

visual inspection (WES 8104), penetration-defect detection (JIS Z 2343 VC-S), and a leak test (0.2 kg/cm^2) without problem.

5. Development of automated welder for vertical Ti cover

Table 2 summarizes the process of manufacturing the mega-float body and applying the Ti-clad lining. As indicated, downward welding with adequate block segmentation and placement can be used to apply Ti-clad steel sheet to the hull during the block manufacturing. A conventional automated welding system would be suitable with only minor modifications.

However, for vertical welding there is no other option but to do the operation in the dry chamber in order to assemble individual units by weld-joining blocks and then join the units to construct the floating body. The height of the area for this operation is currently 2 m, but in the future will be 5 m. An automated welder is used in order to reduce the time needed for the operation and ensure weld quality. Since no suitable automatic welder was readily available, a new one was developed. **Fig. 5** shows a schematic rendering of the new automated welder. It was developed in 1995 and performance-tested in 1996, both on-site under the influence of natural wave vibrations, and in a laboratory with simulated vibrations. The basic specifications of this automated vertical welding system are as follows.

(1) The system was attached to the floating body or the chamber in a frame structure equipped with welding torch and guide roller.
(2) The position of the torch tip was determined by the push roller (front/back position) and the guide roller (left/right position), as shown in **Photo 5**.
(3) A vertical range of 4 m was assumed, and the system was a remote-controlled pendant type.
(4) The system was a twin-torch type to allow simultaneous welding of both sides of the Ti cover plate (width 35 - 50 mm).
(5) A push roller system was employed to reduce the interim welding process.

Table 2 Mega-float body manufacturing process and Ti-clad lining operations

	Process	Lining location	Working environment	Weld position
(1)	Block production	Block side wall	Manufacturing plant	Downward
(2)	Unit composition	Block side wall	Dry dock	Vertical/side
(3)	Joining floating bodies	Welding between floating units	On-site floating chamber	Vertical/side

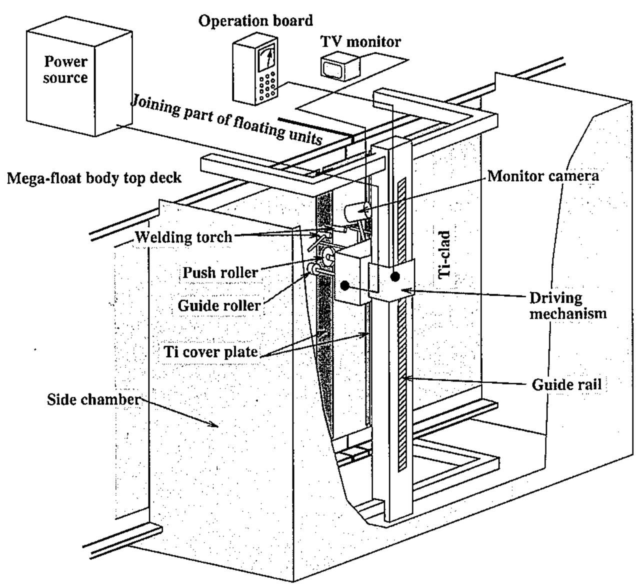


Fig. 5 Automated welder for use at marine service site

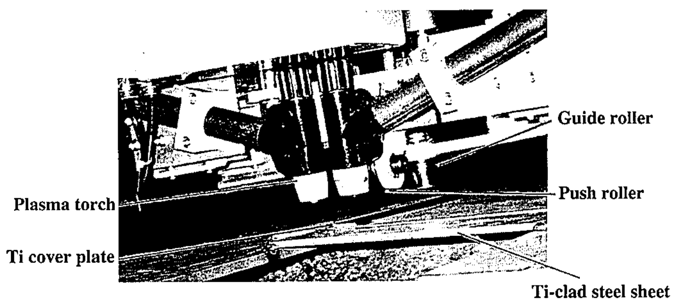
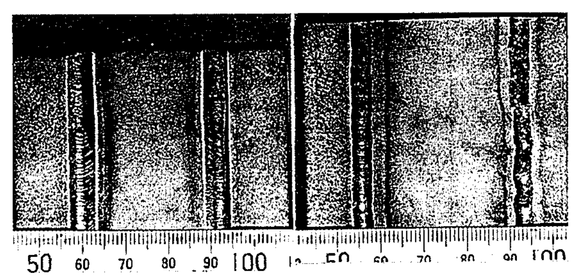


Photo 5 Torch and rollers of automated welder



(a) Automated weld (plasma) (b) Manual weld (TIG)

Photo 6 Comparison of beads of automated welder and manual weld

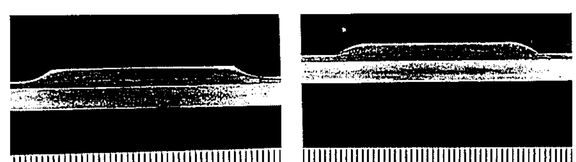


Photo 7 Comparison of bead cross-sections of automated welder and manual weld

(6) A plasma weld system was employed to minimize arc interference and improve weldability.

The weld test results were evaluated by visual inspection, penetration-defect inspection, and cross-sectional observations. **Photo 6** shows the weld beads, and **Photo 7** the cross-sections. The inspections showed that the performance characteristics of the newly developed automated vertical welding system were satisfactory.

A laboratory test in 1996 under simulated wave conditions (effective wave height 50 cm with 6.5 s cycles) verified that the welding was effective under this threshold working condition at sea provided the weld speed was no more than 15.5 cm/min.

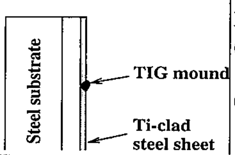
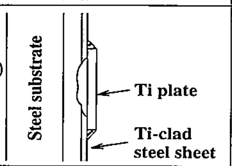
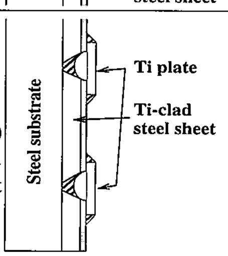
6. Development of on-site repair procedure

Normally, the large-scale floating body would be moored in a relatively calm area protected by a breakwater, and thus there would be little likelihood of accidents involving large ships. Nonetheless, its hull might still be struck by driftwood and other floating debris, as well as by small craft of various kinds, including boats carrying the maintenance staff, and such impacts might damage the Ti-clad steel sheet. The repair procedure required would depend on the severity of the damage, as summarized in **Table 3**. The repairs would have to be performed in a dry environment, using the side chamber.

The verification test repair operation in 1996 involved medium-level damage. As shown in **Fig. 6**, Ti-clad steel sheet test pieces with areas of deliberately-introduced damage (diameter 150 mm) were fastened to the side of the floating body's hull for a certain time and then were repaired. **Photo 8** shows the initial setup of the test, and **Table 4** the specifications of the model damage. **Photo 9** shows the damaged area before the repair, and **Photo 10** that afterwards. The repair welding took place without mishap.

The center of the model damage (diameter 150 mm) was set at the water surface level and kept there for nine months. During this exposure period, a layer of mussels and seaweed steadily built up over the model defect part. The protection potential at the onset of the immersion was –970 mV vs. SCE. No rusting was detected by

Table 3 Damage classifications of Ti-clad steel sheet and corresponding repair procedures

Damage classification		Repair method
Small damage (less than 3 mm) to Ti part only		Mound welding (1) Clean surface of damaged part (2) TIG mound welding
Medium damage (more than 3 mm) remains in Ti-clad steel sheet		Ti sheet to be welded (1) Attach Ti plate to damaged part (2) TIG corner welding of a Ti plate
Extensive damage (more than 3 mm) extending beyond Ti-clad steel sheet		Partial replacement of Ti-clad steel sheet (1) Cut out damaged part of Ti-clad steel sheet (2) Weld fresh Ti-clad steel sheet over side surface (3) TIG corner welding of a Ti plate

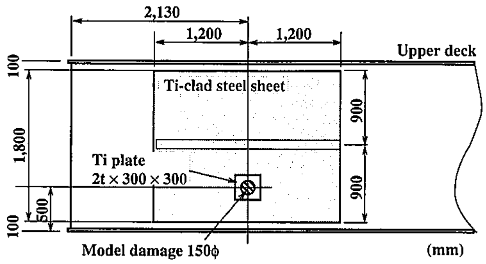


Fig. 6 Model damage for testing of on-site welding repair

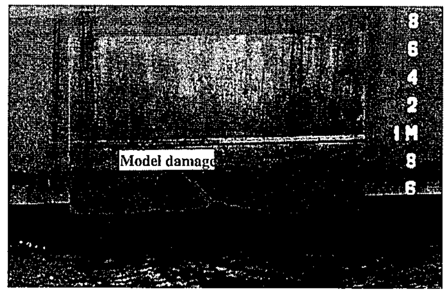


Photo 8 Model damage for testing of on-site welding repair

Table 4 Specifications of model damage

Term	Condition
Damage size	Diameter 150 mm
Damage depth	1.5 mm (reached steel)
Damage location	Damage center at sea level
Damage-exposed period	9 months (October 1995 to July 1996)
Size of Ti sheet for repairs	250 mm × 250 mm × 2 mmt

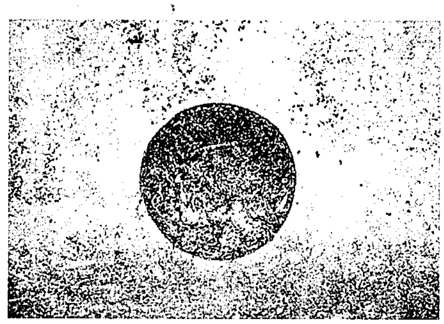


Photo 9 Model damage prior to repair (after removal of adhering marine creatures)

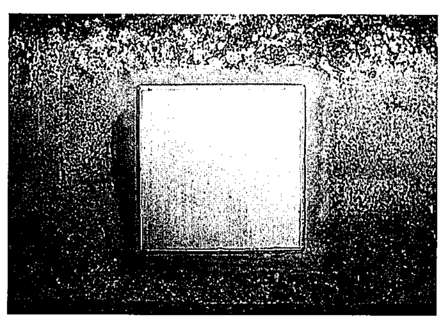


Photo 10 Model damage after on-site repair with Ti plate

the inspection in the dry chamber (Photo 9). Corrosion depth monitoring by molding showed no evidence of thinning anywhere within the circular model defect. We concluded that the underwater galvanic corrosion protection was successfully inhibiting corrosion due to contact between unlike metals (Ti and steel).

7. Test of corrosion protection with Ti foil

In October 1997, the use of Ti foil to protect the atmospheric part of the mega-float body against corrosion was tested (**Photo 11**). First, Ti foil 0.1 mm thick was glued to 0.7 mm thick butyl rubber. At the installation site, this was spread over the surface of the floating body with a roller by detaching the detachable sheet. Each sheet of Ti foil was 540 mm × 180 mm in size. Adjacent Ti foils were allowed to overlap at the edges. Two types of substrate surface conditions were tested: one was a surface from which the paint-coating layer was completely removed with a disk-sander, and the other was a paint-coated surface.

The test results showed that it was easy to apply the Ti foil to smooth flat substrate surfaces, but not to areas with complicated geometry (e.g., the weld part) because of the stiffness of the foil. When the applied Ti foil was inspected after six weeks, there was no sign of delamination or swelling. Although the long-term effectiveness of this method still has to be demonstrated, its cost is competitive with that of currently available heavy-duty paint coatings[8]. For this reason, it will probably be adopted as a corrosion-protection method for the part of the mega-float body that is exposed to the air, if a procedure for applying it to a large area can be developed.

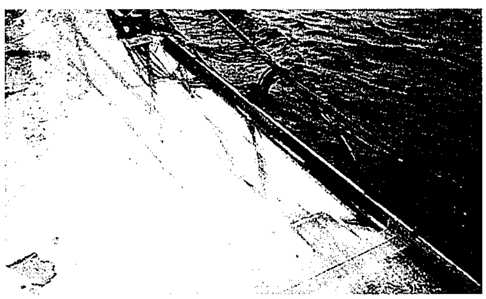


Photo 11 Sheet lining of Ti part

8. Conclusions

The mega-float body can be used as a platform for any number of infrastructures, including large international airports, medium-sized local airports, heliports, port facilities, power stations, petroleum and LNG storage facilities, bridge piers, municipal waste-processing and sewage-treatment plants, residential buildings, office buildings, parks, shelters against natural disasters, hotels, sports and leisure complexes, fish-farming facilities, and fish-products processing plants. Some of these structures have already been built, but most are still in the planning stage.

The ocean plays an important role in the environment. While the expansion of human activities into oceanic regions seems inevitable, this step must be taken without harming the environment. The mega-float structure will be an important means of ocean development. Because the maintenance costs of social infrastructure are continually increasing, the construction of maintenance-free infrastructures that can remain in service for a century or more is essential for the sake of future generations. From the standpoint of life-cycle analysis, there is an urgent need to develop technologies that will make highly-durable low-cost steel structures feasible.

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