RENOVATION OF A CONCRETE WATER TANK
IN CHIBA PREFECTURE, JAPAN

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ABSTRACT

The paper describes the renovation of a circular concrete water tank that had suffered significant deterioration in its dome. After a feasibility study, it was determined that the most desirable solution consisted of the replacement of the existing concrete dome with one made of structural aluminum. The key features of the construction work including existing dome demolition and installation of the new one are herein presented with the intent of providing a case study to engineers, contractors and owners facing similar challenges.

Key words: structural aluminum, circular tank, concrete, dome, renovation.

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INTRODUCTION

A circular concrete water tank in Chiba Prefecture, Japan, constructed over 30 years ago, had experienced a high level of deterioration due to steel reinforcement corrosion. The deterioration problem was most severe in the reinforced concrete (RC) dome and was probably originated by water evaporation on the inside and acid rain on the outside. The original mix design and concrete strength is shown in Table 1.

The Municipal Authority, owner of the structure, decided for its renovation that included repair of the wall and replacement of the dome. The original structure (see Figure 1) consisted of an RC foundation slab, prestressed concrete (PC) wall, and RC dome, with concrete compressive strengths of 30, 36 and 24 MPa, respectively. The deteriorated RC dome was reinforced with No.4 (13-mm) 295-MPa yield strength steel bars at 300 mm spacing, with a 40 mm concrete cover. No inner surface coating protection was used. Concrete deterioration in the RC dome is shown in Figure 2. The internal corrosion problem was probably accelerated by the presence of chloride ions in the drinking water, the measured level of which was about 2 ppm.

Some of the geometrical characteristics of the structure were as follows: inner diameter equal to 27.0 m; water depth equal to 8.0 m; effective water volume equal to 4500 m³; and reinforced concrete thickness equal to 100 mm (dome) and 200 mm (wall). The PC wall – RC foundation slab connection was of the bearing hinge type.
FEASIBILITY STUDY

A feasibility study was conducted at the onset of the project to determine the most effective renovation strategy. The results of this phase are summarized in Table 2 for the methodologies related to the RC dome renovation. The replacement option with an aluminum alloy structure was finally selected for the dome, while the wall was simply restored with anti-corrosion painting. The owner felt that this solution was the most efficient in terms of its cost (first cost and life cycle), time of construction, and ease of maintenance. The following sections describe the five-month renovation project that occurred between November 2000 and March 2001.

DISMANTLING OF THE EXISTING RC DOME

The challenges of the dome dismantling operation, approximately 64 m$^3$ of material, were to avoid partial collapse and damage to the foundation slab as well as the tank accessories such as the pipelines. A battery of concrete sawing machines was employed. The saws were mounted along guides as shown in Figure 3. Depending on the demolition phase, up to five saws operated at the same time. The cutting sequence was determined by accurate numerical analysis using the finite element method (FEM). Several FEM simulations were conducted to take into account the effect of the progressive demolition and to predict maximum compressive and tensile stresses in the remaining concrete. Cutting started at the center of the dome and slices of reinforced concrete, 1.5 m in width and 2.0 m in length, were progressively removed using a crane (see Figure 4). The dismantling operation that proceeded in circles lasted for approximately two weeks. Figures 5 and 6 show work in progress at eight and 13 days, respectively. Progress over
time in terms of cut length is plotted in Figure 7 where for every workday, the number of concrete saws in use is also displayed.

During the described operations, the strain in the concrete was monitored to ensure the stability of the structure. The dead load of the dome that generates the strain field is 360 kg/m². Figure 8 shows a plot of recorded strain readings on both the outer and inner concrete surfaces of the dome as a function of the demolition date. The gages were attached close to the edge of the dome, since it represents the most critical location. The field measurements confirmed that the maximum tensile concrete stress experienced during the demolition was in the range of 2.0 MPa as predicted in the FEM analysis.

The adopted demolition technique for dome dismantling was proven efficient, safe and rapid. One of its advantages was in that no contamination of the internal part of the tank occurred. Using this demolition technique, it would be possible to leave the tank in operation with the temporary installation of a membrane cover over the stored water as schematically shown in Figure 9.

**CONSTRUCTION OF THE ALUMINUM ALLOY DOME**

The design of the aluminum alloy dome was conducted in accordance with the Design Code for Aluminum Architectural Structure issued by the Japan Institute of Architects (JIA 1996). The selection of the type of aluminum alloy was determined by strength considerations based on the design loads. In particular, the live and wind pressures considered for design of the dome panels
and the supporting frame were 0.5 kN/m² and 1.7 kN/m², respectively. As a result of the design calculations for the supporting frame, aluminum H-shapes were selected as inner beams, 3.0 m in length, having the following dimensions: 152 mm in height, 125 mm in width, 2.5 mm in web thickness, and 5.3 mm in flange thickness. Similarly, H-shapes were selected for the tension members, 3.0 m in length, with the following dimensions: 152 mm in height, 125 mm in width, 16 mm in web thickness, and 9 mm in flange thickness. The dome panels of triangular shape, also with 3.0 m long sides, had a thickness of 1.3 mm. The principal dimension of the aluminum dome was 25 m in radius and 3.3 m in rise with a total weight of only 5 tonnes.

To position the aluminum alloy dome on the PC wall, a cast-in-place concrete bearing seat was constructed as shown in Figure 10 (the concrete mix design and compressive strength are given in Table 1). The bearing was reinforced with No. 4 (13-mm) 295-MPa yield strength steel bars at 200 mm spacing. The separation between new and old construction is shown by a dashed line in the figure. The high-quality concrete used was considered satisfactory against chloride ions penetration as was the existing PC wall.

The construction of the structural aluminum dome consisted of three phases: factory manufacturing, on-site pre-assembly, and on-site installation.

**Factory Manufacturing-Work.** Manufacturing of the aluminum panels and structural shapes was undertaken in Houston, Texas. All elements were factory-painted in Japan (see Figure 11) using an epoxy resin coating for inside surfaces and a fluoro-ethylene resin coating of the outside...
surfaces. The coatings complied with Japanese standards for paints in contact with potable water (JDWA 1989).

**On-Site Pre-assembly Work.** All dome components were shipped to the construction site. Temporary scaffolding for pre-assembly was only necessary for the junctions of the frame members where bolting operations were conducted (see Figure 12). This dome was assembled without welds, facilitating quality control and inspection. Calibrated torque-wrenches were used for securing the bolts with a constant torque force of 98.1 kN-m.

The dome frame was assembled by adding peripheral members and simultaneously adjusting the height of the scaffolding. The panels were installed using tap bolts for connection to the frame (see Figure 13). This assembly phase was concluded with a field water shower test. The dome, as assembled, passed the field water test.

**Final Installation.** The dome was hoisted in a “single pick” using a 120 tonnes crane (see Figure 14) and set in place in only three hours. Anchor bolts were used to secure the dome to the PC wall. Non-shrinkage mortar was used to seal the joints. End plates were installed over the dome/wall interface to secure water tightness along the perimeter (see Figure 15). The thermal expansion was accommodated by providing slide bearing seats with an allowable displacement of about 25 mm. Finally, a walkway was installed to facilitate future inspection and maintenance (see Figure 16).

The result of the completed renovation project can be seen in Figure 17.
CONCLUDING REMARKS

Several thousand water tanks similar to the one discussed in this paper are in existence in Japan. Generally, the RC foundation slabs and the perimeter PC walls are sound and deterioration problems are confined to the RC dome.

The replacement of deteriorated RC domes with structural aluminum systems appears to be an efficient solution in terms of cost, installation, performance, and long-term maintenance. This project demonstrated some of the key characteristics of the proposed technology, including the existing dome demolition.

ACKNOWLEDGMENTS

Sincere gratitude is extended to the government authorities of Choshi-City, Chiba Prefecture, who agreed to adopt this solution for the first time in Japan.

REFERENCES

Table 1: Mix design and concrete strength

<table>
<thead>
<tr>
<th>Application</th>
<th>Nominal strength (MPa)</th>
<th>Slump (cm)</th>
<th>Gravel max size (mm)</th>
<th>W/C (%)</th>
<th>S/Total Aggregate (%)</th>
<th>Unit weight (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Original Dome</td>
<td>24</td>
<td>8</td>
<td>20</td>
<td>56.5</td>
<td>44.2</td>
<td>273</td>
</tr>
<tr>
<td>New Bearing</td>
<td>30</td>
<td>8</td>
<td>20</td>
<td>48.5</td>
<td>42.4</td>
<td>324</td>
</tr>
</tbody>
</table>

Note: * = Ordinary Portland Cement
Table 2: Comparison of renovation alternatives

<table>
<thead>
<tr>
<th></th>
<th>Concrete repair and inner anti-corrosion painting (1)</th>
<th>Replacement with new RC dome (2)</th>
<th>Replacement with aluminum structural dome (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General description</strong></td>
<td>Spraying anti-corrosion painting over entire inner surface after treatment of exposed corroded reinforcing bars</td>
<td>Construction of new RC dome after dismantling of existing one</td>
<td>Construction of aluminum alloy dome after dismantling of existing one</td>
</tr>
<tr>
<td><strong>Features</strong></td>
<td>Scaffolding for the entire area of the inner tank. Limited reliability resulting from treatment of exposed reinforcing bars only</td>
<td>Scaffolding for the entire area of the inner tank. Life expectancy equal to that of old dome</td>
<td>No internal shoring. High anti-corrosion resistance. Enhancement of seismic resistance due to light-weight</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Construction period</strong>*</td>
<td>Short (approx. 4 months)</td>
<td>Long (approx. 7 months)</td>
<td>Shortest (approx. 3.5 months). Simultaneous work for dismantling RC dome and assembling aluminum alloy dome</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>High. Necessity of re-repairing if deterioration continues</td>
<td>Medium. Necessity of maintenance approximately in 20 years</td>
<td>Low. Ease of maintenance since dome components can be removed</td>
</tr>
<tr>
<td><strong>Appraisal score</strong></td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

* = Out of service – Tank not available for use
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Total length = 615 m

No. of concrete saws

Date

Cut length (m)
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