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# APPLICABILITY OF FIBER REINFORCED PLASTICS TO HYDRAULIC GATES

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## ABSTRACT
Following the results of surveys targeting related government ministries and agencies, industry organizations, local governments, etc., it has become clear that Fiber Reinforced Plastics (FRP) have been applied to members of hydraulic gates since the 1960s with over 400 structures now existing in Japan. Fifty FRP gates were visually inspected. Though they have been only lightly maintained over 30 years, little deterioration is evident. Results of durability tests with FRP specimens in the laboratory indicate that FRP for hydraulic gates has satisfactory water and corrosion resistance, though appearance gradually deteriorates from exposure to ultraviolet light.

## KEYWORDS
Fiber Reinforced Plastics (FRP), Hydraulic Gate, Durability, Weather Resistance, Corrosion Resistance

## 1. INTRODUCTION

Hydraulic gate facilities are main structures in river-ways and play key roles in flood control and water utilization works. At present, mainly steel materials have been used for these facilities. Though these structures are always exposed to severely corrosive environmental elements, there are few effective anticorrosion engineering options. Hence, it is desirable to develop advanced materials having excellent corrosion resistance in order to reduce the labor and cost for maintaining hydraulic gates. In this paper, present situations of FRP that have been utilized as hydraulic gates in Japan were investigated and problems for bringing FRP to market were clarified in order to promote the application of FRP for hydraulic gates. In addition, field studies were carried out on 53 in-service FRP hydraulic gates in order to understand their actual conditions and performance. Furthermore, long-term durability of FRP for hydraulic gates was examined by accelerated weathering and water immersion tests.

## 2. MARKET RESEARCH OF FRP HYDRAULIC GATES IN JAPAN

In association with the main Japanese manufacturer, construction results of FRP hydraulic gates in Japan were investigated. Results of these investigations showed that 438 FRP gates were initiated from 1961 to 2002 in Japan but of these, the existence of only 59 FRP gates was confirmed. The reason for this low number of verified FRP gates is because many of them were delivered to general contractors and are therefore now impossible to track. Figure 1 shows initial construction data of FRP hydraulic gates arranged by construction year. This data shows that more than 80% of total FRP gates were constructed before 1990, whereas construction in recent years has significantly declined. The styles of FRP gate adopted in Japan are slide gate, flap gate, roller gate, swing gate, miter gate, sliding gate and angle chute; most gates are compact in size. The area is smaller than 4.0 $m^2$ on almost 90% of adopted FRP door bodies. It is assumed that FRP was difficult to apply to large door bodies because FRP has low elastic modulus and is flexible. In the present state, it may be effective to promote the advantages of FRP by limiting targets to comparatively small-scale (such as 10 $m^2$ or less) hydraulic gate facilities.

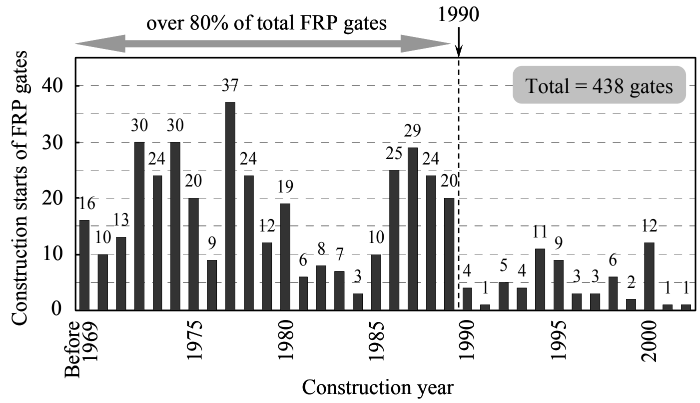



**Figure 1: Construction Starts of FRP Hydraulic Gates in Japan**

In order to examine the marketability of FRP hydraulic gates, questionnaire surveys were carried out targeting related government ministries and agencies, industry organizations, local governments, and so on. The questionnaires consisted of questions about durability, abrasion resistance, ease of installation, maintenance, weather resistance, strength, corrosion resistance, initial cost, and running cost for FRP hydraulic gates. The results of the questionnaire showed that low visibility of FRP within the FRP hydraulic gates market has been one of the obstacles against its increased use.

## 3. LONG-TERM DURABILITY OF FRP IN RIVER ENVIRONMENTS

In order to confirm the applicability of FRP to members of hydraulic gate facilities, age deterioration of in-service FRP gates was investigated.

### 3.1 Field Studies on Existing FRP Hydraulic Gates

Field studies were carried out on 53 FRP hydraulic gates which were in service. Material degradations of FRP members caused by river water or ultraviolet rays were evaluated visually. Results of the visual inspections show all FRP gates had no major deterioration except for slight discoloration and water stain despite the fact that they were hardly maintained for 30 years. Thus, FRP gates seem to be more durable than steel gates after an equivalent period of time.

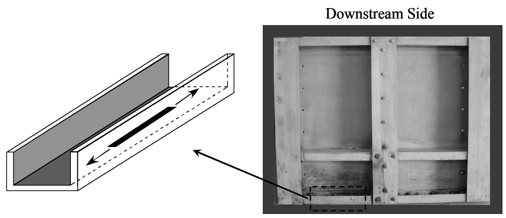
### 3.2 Disassembling Investigations on an FRP Door Body

An FRP door body which had been used as a sluice gate on an agricultural waterway was selected and examined (see Table 1).

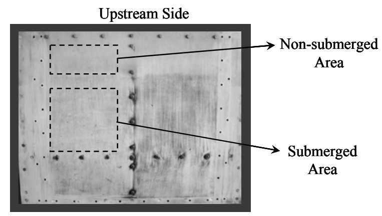
**Table 1: Overview of FRP Hydraulic Gate Selected for Strength Tests**

| | | |
|---|---|---|
| **Construction Year** | before 1969 |  |
| **In-service Period** | more than 35 years | |
| **Gate Style** | slide gate | |
| **Dimensions** | 1.15m x 1.00m | |
| **Applied FRP** | door body, door stop | |
| **Forming Method** | hand lay-up | |
| **Operating Situation** | full-time operating | |
| **Transformation by Water Absorption** | N/A | |
| **Erosion Damage** | N/A | |
| **Degradation** | water stain<br>discoloration | **Panoramic View** |

Tensile tests were carried out by using a main girder channel and a skin plate of a dismantled door body. From the channel and sections of both the submerged area and non-submerged area of the skin plate, five test specimens were cut into pieces 8 mm thick, 25 mm wide, and 250 mm long respectively. For comparison, tensile tests were also similarly carried out on another FRP channel and laminate that were newly fabricated with exactly the same laminate composition as that of the obtained old door body. The sampling method of the FRP door body for the tensile test is shown in Figure 2. After testing, specimens were examined by scanning electron microscope (SEM), energy dispersive X-ray spectrometer (EDS), Fourier transform infrared spectrophotometer (FT-IR), and so on.




(a) Main Girder




(b) Skin Plate

**Figure 2: Sampling Methods of FRP Door Body for Tensile Test**

Table 2 shows a part of the results. Some data spread on tensile strength, which is a weakness of FRP material, was recognized. A future challenge is to reduce such data spread. In any case, it was confirmed that the mean values of tensile strength and modulus were almost the same between the two FRP laminates. Results of instrumental analyses for specimens after tensile tests did not indicate significant deterioration of the FRP door body.

**Table 2: Comparison of Tensile Properties between FRP Skin Plate after Use for 35 Years and Newly Fabricated Laminate**

| Specimen No. | After Use for 35 Years | | | | Newly Fabricated | |
|---|---|---|---|---|---|---|
| | Non-Submerged Area | | Submerged Area | | | |
| | Tensile Strength [MPa] | Tensile Modulus [GPa] | Tensile Strength [MPa] | Tensile Modulus [GPa] | Tensile Strength [MPa] | Tensile Modulus [GPa] |
| **1** | 168.49 | 17.10 | 152.35 | 15.62 | 161.69 | 15.04 |
| **2** | 156.71 | 15.25 | 149.60 | 15.31 | 168.82 | 15.08 |
| **3** | 144.87 | 15.57 | 149.91 | 23.61 | 162.90 | 17.66 |
| **4** | 135.63 | 16.49 | 148.65 | 15.25 | 167.19 | 16.43 |
| **5** | 135.63 | 15.83 | 149.72 | 15.55 | 173.62 | 15.86 |
| **Average** | 148.27 | 16.05 | 150.04 | 17.07 | 166.84 | 16.02 |

# 4. DURABILITY TESTS OF FRP FOR HYDRAULIC GATES

Generally, FRP for hydraulic gate members is produced using the hand lay-up, resin injection, or pultrusion molding methods. Matrix resins of those FRP are epoxy resins, unsaturated polyester resins, or vinylester resins, with glass fibers used as reinforcement. General characteristics of FRP for hydraulic gate members are shown in Table 3. In order to obtain basic knowledge about the long-term durability of FRP, accelerated weathering tests and water immersion tests were carried out. FRP laminates manufactured by hand lay-up, resin injection, and pultrusion were used as testing samples. Dimensions of test specimens were 4–10 mm thick, 15 mm wide, and 200 mm long. In accelerated weathering tests, specimens were put into an accelerated weathering tester in the laboratory and exposed to xenon-arc sources. Changes of properties with UV irradiation were evaluated by glossiness and color difference on specimen surface, flexural strength, and flexural modulus. In water immersion tests, the same specimens as the accelerated weathering tests were immersed in water at 20–25°C. Changes of properties with penetration of water were evaluated by weight change, flexural strength, and flexural modulus.

In Figure 3 (a), gloss retentions in all cases were significantly reduced from the beginning of exposure and then decreased to less than 20% of the original glossiness at about 2500 hours exposure. On the other hand, Figure 3 (b) shows that the flexural strength of each FRP sample barely changed from before and after exposure to ultraviolet light for 2500 hours, though pultrusion FRP strength showed some loss. From these results, it was determined that degradation of FRP by ultraviolet rays had occurred only at the surface after 2500 hours exposure, indicating that FRP's strength remained virtually intact. It is supposed that such degradation in FRP surface by ultraviolet light can be chemically improved by coating the FRP surface with, for example, a gel coating with high resistance to UV radiation.

**Table 3: General Characteristics of FRP* for Hydraulic Gate Members**

| Molding Method | $V_f$ [%] | Mechanical Properties | | | | | Thermal Properties | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Tensile Strength [MPa] | Tensile Modulus [GPa] | Flexural Strength [MPa] | Flexural Modulus [GPa] | Compression Strength [MPa] | Coefficient of Linear Expansion [$10^{-5}$/°C] | Thermal Conductivity [W/mK] | Specific Heat [J/gK] |
| **Hand Lay-up** | 25 - 40 | 80 - 120 | 7 - 10 | 120 - 180 | 7 - 9 | 120 - 170 | 3 - 4 | 0.17 - 0.23 | 1.38 |
| **Resin Injection** | 25 - 40 | 80 - 120 | 7 - 10 | 120 - 180 | 7 - 9 | 120 - 170 | 3 - 4 | 0.17 - 0.23 | 1.38 |
| **Pultrusion** | 55 - 85 | 500 - 900 | 20 - 40 | 590 - 900 | 20 - 35 | 250 - 500 | 0.6 - 0.8 | 0.29 - 0.52 | 1.05 - 1.26 |

*matrix: unsaturated polyester resin, reinforcement: glass fiber

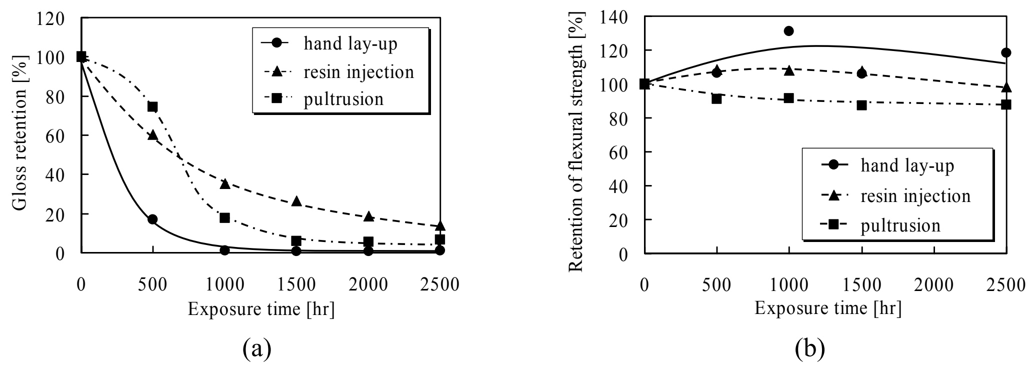



**Figure 3: Results of Accelerated Weathering Test; Gloss Retention (a) and Retention of Flexural Strength (b) of FRP Exposed to Laboratory Xenon-arc Sources**

In the immersion tests for 2500 hours, the largest value of material swelling rates was +0.61% and that of weight changes was about +1.4%. In three-point bending tests, the flexural strength of FRP decreased slightly. It seemed that the strength degradation of FRP was caused by swelling due to water absorption. In this immersion test, swelling and strength degradation of FRP did not exceed the permissible limit, since water absorption of FRP was very small.

The results of durability tests clarified that FRP for hydraulic gates has satisfactory water resistance and corrosion resistance, while appearance gradually deteriorates from exposure to ultraviolet light. Therefore, it seems that FRP is especially suitable for hydraulic gates which are usually submerged in water.

## 5. CONCLUSION

The present study revealed that FRP is especially suitable for hydraulic gates usually submerged in water since they have excellent durability and water or corrosion resistance. For the future, it will be necessary to formulate guidelines for the application of FRP to hydraulic gate members in order to improve the visibility of FRP and promote its utilization in the hydraulic gates industry.

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