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Study on application of fiber-reinforced concrete in sluice gates

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HIGHLIGHTS

- The sluice gate is made by concrete and applied it in hydraulic engineering.
- The concrete gates meet operational needs and watertight seals functioned normally.
- The concrete gate is as cheap as one-fifth cheaper to produce than cast iron gates.

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ABSTRACT

A sluice gate is a primary hydraulic structure in water discharge and storage facilities. Steel sluice gates are often stolen when global metal prices are high. Thus, this study proposed using fiber-reinforced concrete to fabricate sluice gates. The material mechanical properties and durability of the fiber-reinforced concrete sluice gates were tested, and field test and feasibility tests were subsequently performed. The compressive strength, flexural strength, and elastic modulus of the concrete used to construct the gates were respectively 99.3 MPa, 18.2 MPa, and 40.0 GPa. In the concrete, the depth of wear by hyperconcentrated flow was 0.5 mm h^{-1} mm^{-2}; the chloride diffusion coefficient was 2.25×10^{-12} m^2 s^{-1}; and the weight loss in the soundness test was 1.02%.

The results of the field testing suggested that the size and weight of the fiber-reinforced concrete sluice gates met operational needs and that the gates maintained their watertight seals and functioned normally during and after several tropical cyclones. Monthly observations revealed no noticeable cracks or rust stains on the gate surfaces. And the difference of properties of fiber-reinforced concrete before and after one year exposure is within ±6%. The fiber-reinforced concrete sluice gates were estimated to be one-tenth cheaper to produce than stainless steel gates and one-fifth cheaper than cast iron gates. The concrete sluice gates can be employed in low-head areas and drainage basins.

1. Introduction

A sluice gate is a hydraulic structure that controls flood water, affords protection against tides, and channels and stores water. Its operation and management is fundamental to ensuring the safety of the lives and property of the general public. The number of sluice gates across Taiwan has been increased since the government performed improvement works on river drainage canals and flood-prone detention basins and pumping stations. Sluice gates in Taiwan are mostly made of metal (including cast iron, black iron, and stainless steel); they are frequently stolen and sold as scrap metal because global metal prices continue to rise, pushing scrap metal prices higher. Such thefts are more common in sparsely populated regions [1]. An additional problem is that bulky steel sluice gates make it difficult to discharge water inside of levees. Malfunctioning sluice gates inhibit efforts to prevent floods, thus threatening public safety and property. This underlines the need to develop nonsteel sluice gates that have lower dead weight, are less likely to be stolen, and can facilitate water discharge.

Concrete is characterized by high strength, density, durability, and modulus of elasticity and low permeability and cost; it also weighs much less than steel. Fiber-reinforced concrete (FRC) is a composite concrete material containing uniformly distributed fibers whose high tensile strength helps to prevent the material from rupturing internally and enables it to withstand the extension of cracks. FRC is thus stronger and more resistant to cracks, impacts, shocks, and abrasion than normal concrete [2–5]. In the present study, concrete was used to construct sluice gates, the mechanical properties, durability, and cost of which were assessed. The findings of this study can be applied in hydraulic engineering.

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2. Design and construction of concrete sluice gates

A sluice gate traverses a river or water course and comprises civil engineering components, a gate unit, and a mechanical lifting system [6]. Specifically, the structure consists of the following: (1) a gate (a movable device that comprises a body structure, frame, and fixation base and is usually made of steel); (2) culvert (embedded underground and crossing flood-prevention roads and levees, it connects discharge canals inside of a riverbank and river drainage structures outside of the bank and comprises one hole at the entrance and another at the exit); (3) lifting device or winch (opens and closes the gate mechanically and is driven manually, electrically, or hydraulically); and (4) derrick (made of metal to connect the gate and the hoist, and built in the shape of a screw thread or trapezoid). Fig. 1 is an illustration of a sluice gate. A sluice gate can be operated either automatically or manually. Automated sluice gates, normally installed on levees and banks to prevent tides and floods, use pressure from water-level differences between the inside and outside of a bank to release their self-weight pressure and prevent tidewater intrusion. Manual sluice gates require human operators to use a winch to actuate a derrick, thereby opening and closing the gate vertically, and are typically installed at ditches or rivers for regional sewage and field irrigation [6]. In this study, the proposed FRC sluice gates were operated automatically.

Because of safety concerns, the sluice gate were installed 739 m away from the starting point of the Houanliao sea embankment at the Mailiao Estuary in western Taiwan (Fig. 2) and 2110 m away from the starting point of the Tanduliao river embankment at the Sandie River in southwestern Taiwan (Fig. 3). For the sake of brevity, the FRC sluice gate installed at the Houanliao sea embankment is referred to herein as the Houanliao sluice gate, whereas that installed at the Tanduliao river embankment is named the Tanduliao sluice gate.

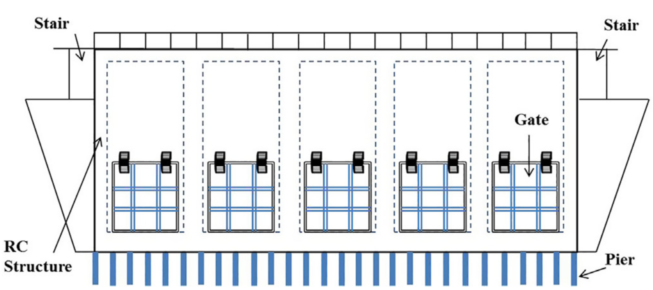

Fig. 1. Illustration of the sluice gate.

2.1. Design of FRC sluice gates

FRC sluice gates were designed in accordance with the technical standards for sluice gates and iron tubes that were developed by Japan Electric Power Civil Engineering Association [6]. The design load of the sluice gates comprised hydrostatic pressure, hydrodynamic pressure during earthquakes, inertial force during earthquakes, mud pressure, buoyancy, impact force from driftwood and other drifting objects, and flowing and static pressure during mudslides. On the basis of two-way slab theory, the maximum principal stress, maximum strain, and shear stress of the sluice gates were estimated, and the amount of steel reinforcement required in the structures was specified. Table 1 shows the results of the strain–stress analysis of the sluice gates.

Two FRC sluice gates were installed respectively at the Houanliao sea embankment and the Tanduliao river embankment, and their respective dimensions were $1700 \times 1700 \times 80\ mm^3$ and $1050 \times 1050 \times 60\ mm^3$ in length, width, and thickness. Both sluice gates contained a double-layered galvanized wire mesh (with wire diameter 2.6 mm, mesh spacing 26 mm, and ultimate tensile strength 2600 MPa) and a 15-mm-thick clear cover. Moreover, 3-mm-thick steel plates were welded within 250 mm in length and width from the center of the lifting lugs to increase the amount of steel reinforcement in the lugs and secure them more tightly.

2.2. Construction of FRC sluice gates

2.2.1. Material composition and specification

The sluice gates comprised the following materials: water; common Portland Type I cement; fine aggregates (derived from natural sand in the Dadu River in central Taiwan; specific gravity of 2.621, water absorption of 1.33%, fineness modulus of 2.98, and silt content of 6.44%); compressed silica fume (imported from Norway; silica content of 92.15%, loss on ignition of 1.75%, and passes 91.93% through a #325 sieve); water-quenched slag powder (produced by CHC Resources Corporation; specific gravity of 2.89); F-class fly ash (produced by the fifth and sixth generators at Tai-

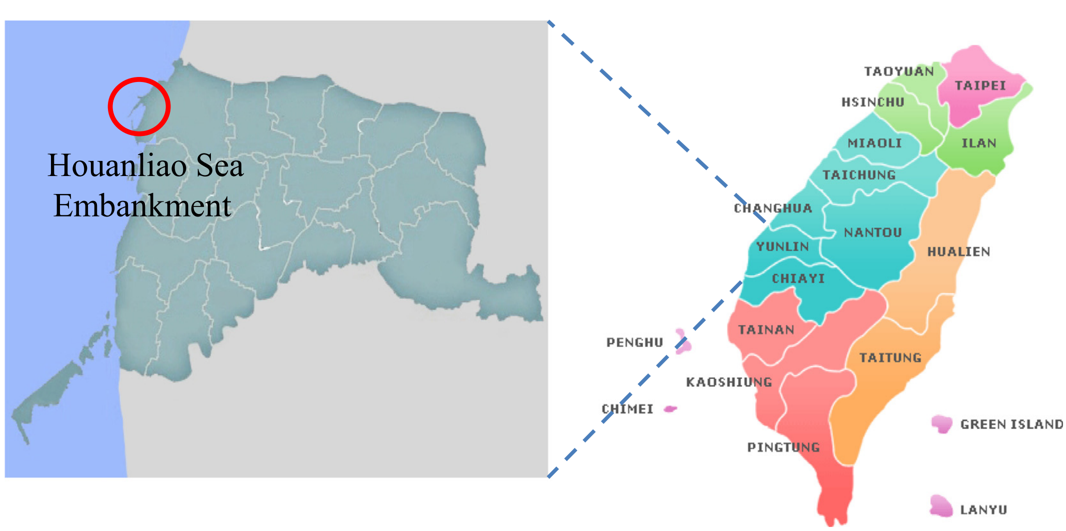

Fig. 2. Location of FRC sluice gate, installed 739 m away from the starting point of the Houanliao sea embankment at the Mailiao Estuary.