Introduction to Hydraulic Gates: History, Types, Operations, and Applications

An Online Continuing Education Course for Engineers

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History and Development

The construction of hydraulic gates was closely related to the development of irrigation, water storage and supply, and river navigation systems. In the early days of hydraulic engineering, water was backed up by small dams and conveyed to side irrigation canals. The excess water was discharged over the dam and conveyed toward agriculture plots or primitive storage areas. As a natural evolution, *movable dams* were built. These movable dams – eventually known as gates - could be temporarily, and mechanically, removed from their normal position to provide passage for excess water, thus permitting greater safety and flexibility in the operation of hydraulic works.

The earliest known man-made canals for water conveyance and irrigation, and for transportation of goods, were built in China. The Dujiangyan, constructed around 256 BCE, is one of the earliest great examples of innovation in hydraulic engineering. Originally conceptualized to prevent flooding in the Min River water basin, it quickly evolved to enhance irrigation and transportation capabilities in the region. This mastery over the storage and conveyance of water propelled ancient China to the top ranks of global productivity and sparked innovation and revolution in all civilizations it contacted. Still in service today, and now protected as a UNESCO World Heritage Site, Dujiangyan still irrigates over 2,000 square miles of farmland, which provides food for over 10 million residents of the region.

Around the year 980, the Chinese pioneered the use of tree trunks (logs), stacked vertically within grooves cut into each side of the bank, to provide temporary blockage/isolation of their well-developed canals. The height of water storage could be manipulated by adding or removing logs to the stack using a system of ropes and various forms of mechanical force. The invention of these new stacked log gates led to the development of locks, first in China and the Netherlands, and eventually around the world. In 1795, the Little Falls canal was completed, making it the first canal with locks in the Americas. The Little Falls Lock also included a first-of-its-kind innovation in gate design. Instead of closing to a flat plane, the two-piece gates closed to form an angle pointing upstream, facing the current, which leveraged water pressure to pin the gates shut, creating a passive watertight seal. This concept would become essential in modern gate design and the principle of operation.

Segment gates first appeared in the 1850s on the Seine and Yonne rivers, and quickly proliferated to other regions such as Germany, the United States, and Egypt, with incremental improvements in locking mechanisms, counterweights, and integral draining features along the way. In the late 19th century and into the early 20th century, a greater variety of gate types and innovations multiplied around the developed world. Segment, section, roller, double-leaf, drum, flap gates, and more became increasingly common in a wide variety of industries, transitioning from mostly wood construction into more modern cast-iron and steel designs. Today, many hydraulic gates are precision fabricated from varying grades of stainless steel and feature engineered rubber and elastomer seals and gaskets for exceptional sealing performance and longevity.

Figure 1 illustrates some of the major milestones in hydraulic gate innovations and development.

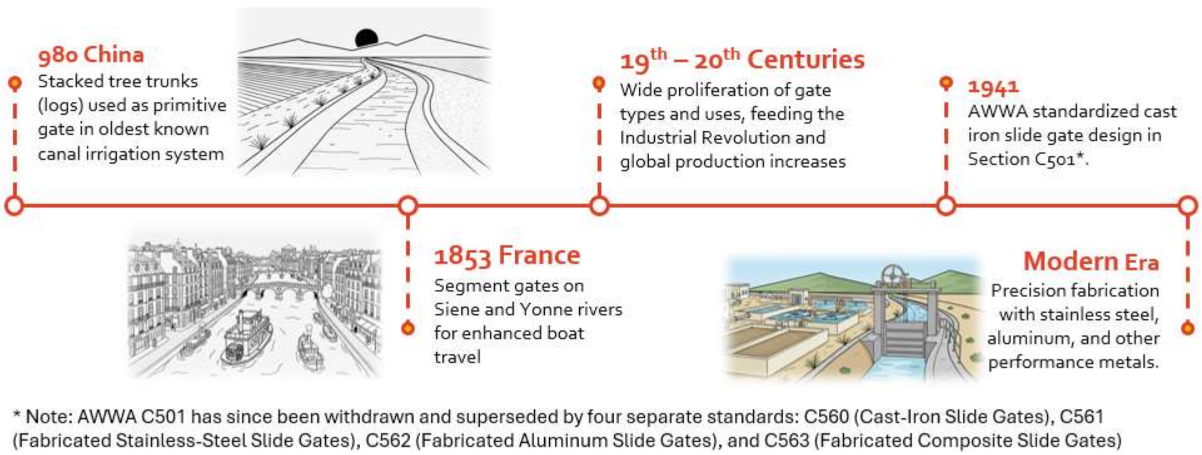


Figure 1. Timeline of Hydraulic Gate Development and Uses.

Modern Hydraulic Gates and Their Uses

Fundamentals of Design

A modern gate consists of three basic elements: a leaf, embedded parts, and an operating mechanism.

1. The leaf serves as the primary bulkhead to water passage, and typically comprises a ‘skin plate’ and reinforcing girders (supports) for added strength and rigidity. The leaf can be either completely flat or have a slight curve for added bearing capacity. In modern gates, the leaf is typically made from stainless steel, cast iron, or fiberglass reinforced plastic (FRP). Attached to the perimeter of the leaf are the seals – rubber or elastomer fittings responsible for the water-tight nature of the system. Additionally, guide elements such as rollers, wheels, bearings, or shoes are also attached to interact with the embedded parts of the system.
2. The embedded parts are the components of the system embedded (or anchored) into the concrete or structure in which the gate resides. The embedded parts comprise primarily the gate frame, slide track, and counter guide elements. Together, they set the limits of leaf travel, maintain gate alignment, and absorb and transfer hydraulic forces and stresses to the structure (or self-contained frame).
3. The operating device, attached to the gate leaf by way of a threaded spindle (also called a stem), provides means for opening or closing the gate. Mechanical devices for opening or closing the

gate, these often include things like handwheels, ratchet levers, gearboxes, hydraulic cylinders, or electric motors.

Figure 2 identifies major components of a typical slide gate.

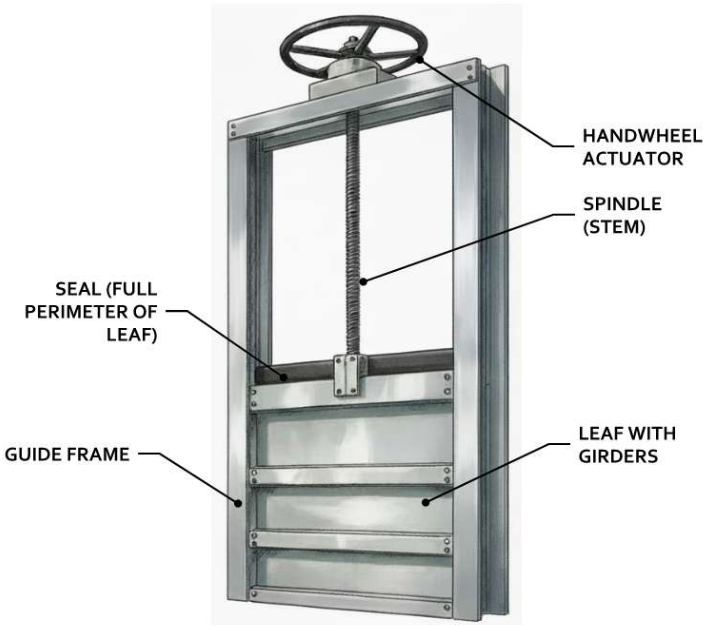


Figure 2. Major Components of a Typical Slide Gate

Codes and Standards

In general, codes and standards are applied to the specific materials of construction that make up various types of hydraulic gates. Some examples from widely acknowledged and industry-standard organizational codes that are meant to ensure quality and consistency include the following:

- American Society for Testing and Materials International (ASTM):
  - A36 - Standard Specification for Carbon Structural Steel.
  - A48 - Standard Specification for Gray Iron Castings.
  - A276 - Standard Specification for Stainless Steel Bars and Shapes.
  - D2000 - Standard Classification for Rubber Products in Automotive Applications.
  - D4020 - Standard Specification for Ultra-High Molecular-Weight Polyethylene Molding and Extrusion Materials.
- American Welding Society (AWS):
  - D1.6 - Structural Welding Code-Stainless Steel

Additionally, the American Water Works Association (AWWA) has produced these four often-referenced chapters, which not only reference the previously listed chapters from ASTM and AWS but also provide guidelines for overall manufacturing, testing, inspection, and performance of vertically-mounted slide gates typically used in water storage and conveyance industries.

- American Water Works Association (AWWA):
  - C560 - Standard for Cast-Iron Slide Gates.
  - C561 - Fabricated Stainless Steel Slide Gates.
  - C562 - Fabricated Aluminum Slide Gates
  - C563 - Fabricated Composite Slide Gates

While most gate manufacturers design and produce their products around these accepted industry codes, it is ultimately a choice of the owner, operator, and/or local authority which material standards and performance requirements they want to enforce.

Uses and Applications

Hydraulic gates typically have three purposes across the various industries in which they are deployed.

1. Service Gates
2. Emergency Gates
3. Maintenance Gates

Service gates are used for continuous or frequent regulation of flow or water level. Emergency gates, sometimes called Guard Gates, are used only for infrequent conveyance shutdown during critical flow events or when downstream equipment vulnerabilities arise. Emergency gates are installed upstream of service gates and are often fitted with motor-operated actuators which respond to connected instrumentation or remote signals from operation personnel. Maintenance gates are used for planned isolation and dewatering of control structures in instances of scheduled maintenance or inspections. Maintenance gates are often not permanent features of their hydraulic structures, but will be deployed only when necessary. Stoplog gates, installed with appropriately sized cranes or hoists, are the most common type of maintenance gate.

The various types of permutations of hydraulic gates are used in a wide variety of applications throughout modern civil, environmental, and industrial engineering projects. These include dams and reservoirs, irrigation canals (agriculture), water and wastewater treatment plants, hydropower facilities, urban stormwater systems, and river diversion projects for flood management and other environmental projects.

Design and Performance

Basis for Selection

One of the most important tasks for a design or consulting engineer is the selection of appropriate equipment for a given application. While there is no explicit or formal guidance for the selection and design of a hydraulic gate, decisions should be made on a comprehensive analysis and consideration of several factors affecting performance and operation. In no particular order, these include;

- Magnitude of hydraulic forces and overall size required
- Quality and Reliability
- Cost
- East of maintenance and functional simplicity
- Structural requirements
- Industry standards and accepted practices

Additionally, selection and design should consider the preferences of the eventual owner and operator of the equipment. Different gate types can achieve similar goals and performance in various applications; therefore final selection of equipment should align with the preferences, familiarities, and skillsets of the primary operators.

Hydrostatics and Design

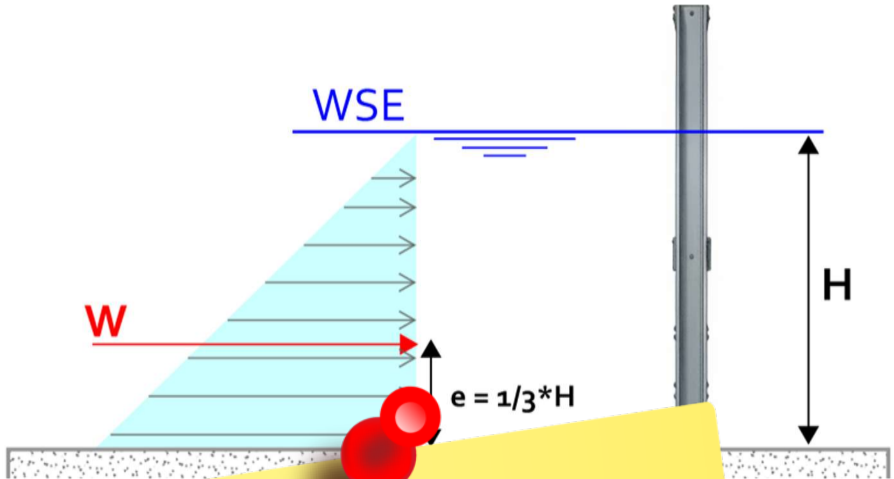
The first step in the design (and often selection) of hydraulic gates in calculation of the hydraulic thrust (water pressure) acting on the gate leaf. With a gate in a closed (or partially closed) position, the adjacent water column exerts a force on the gate leaf, pushing the leaf and perimeter seals against the gate frame, creating a watertight closure and blocking water passage. The maximum value of this pressure on the gate, and the basis for design, typically occurs when the gate is fully closed, and the water level is at its maximum value. In applications where water may be present on both sides of a closed gate, the maximum head is calculated as the difference in opposing forces in the most unfavorable unbalanced condition expected to exist.

The magnitude of the force, greatest at 1/3 the height of the water column (‘e’ in Figure 3 below), is determined with the following equation.

$$W = 0.5\gamma B H^2 \qquad \textit{Eq. 1}$$

Where;

γ= specific weight of water, 62.4 lbs/ft^3
B = width of gate leaf, ft
H = Height of water column, ft
W = Static pressure, lbs



Alternatively, ... ulate the maximum static head for a gate ... mum expected flow rate in the structure, a ... ces and inform their product design ... e with Equation 2;

Eq. 2

Where;

H = Height of wate...
S = Height from inv...
H_s = Static Head on...

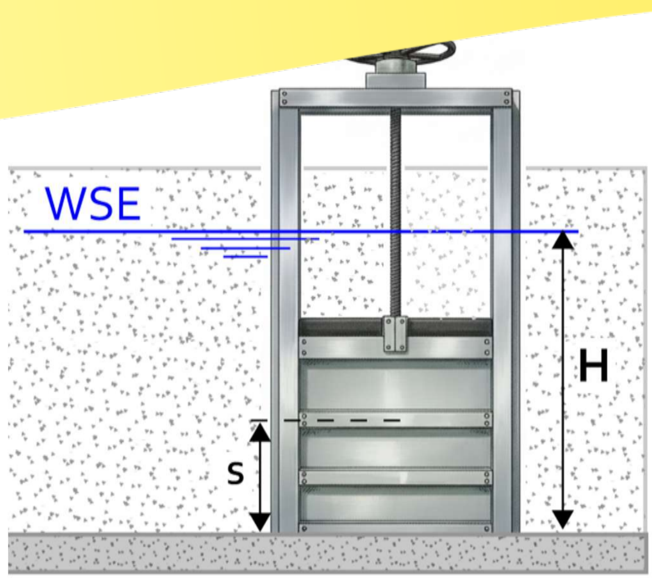


Figure 4. Static Head on Gate