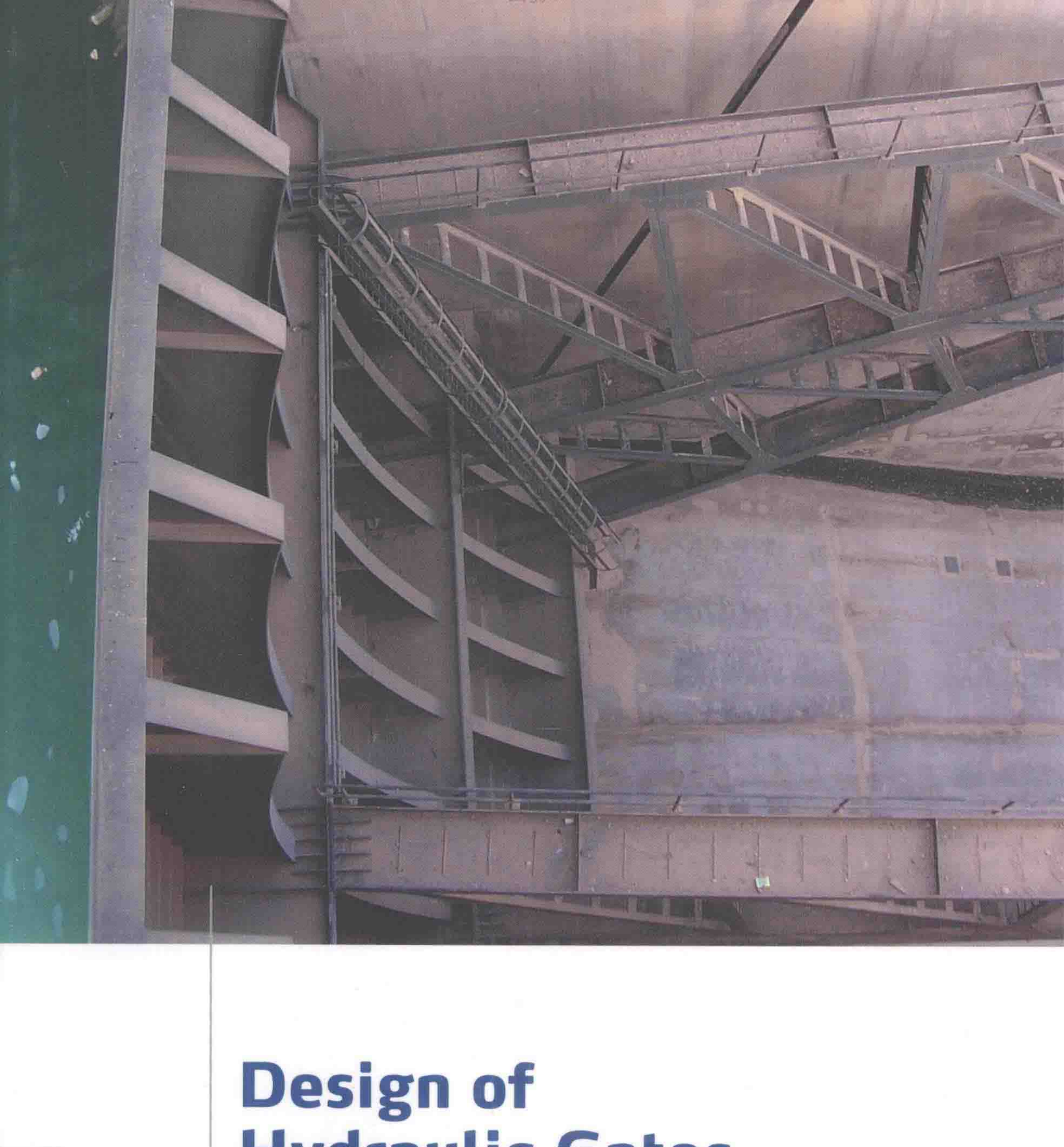

Design of Hydraulic Gates

Paulo C.F. Erbisti

2nd Edition

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Design of Hydraulic Gates, 2nd Edition

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Preface

This book is a *vademecum*, an indispensable companion, for those dealing with hydraulic gates and their reliability. The 17 chapters of this second revised English edition include a comprehensive account of gate type selection, design, manufacture, installation, and operation based on the author's 46 years of experience. It also contains a fine *tour d'horizon* of historic gate development including the latest technological advances.

Dam safety largely depends on the safety of their gates. More than one third of all large dams are gated; and among them are most high hazard dams regulating floods and other water releases. In an age of building ever larger and higher dams, the rate of gated dams is increasing, the more so as for a society caring about the efficient use of water, the flexibility of operation becomes an ecological attribute of gates too. An extreme case is the dam on a large river where dam safety and the safety of the chain of spillway gates are practically alike.

Safety of gates merits special attention of prime concern. Therefore it is so vital that a revised book now comes on the market, which contributes to closing a gap in the rather limited literature on hydraulic gates and their associated equipment.

There is another basic quality concerning the safety of a gated hydraulic structure, and this is that a gate is a so-called "man-machine system" as compared to an ungated structure, which, in terms of reliability concepts, is a predominantly structural system. What this means is that a man-machine system is more vulnerable to the implications of human action, and therefore needs a higher level of safety redundancy for being in control of incidents or failures.

This quality implies that the satisfactory operation of a gate system depends on a reliable interaction of a multitude of components starting with the instantaneous reporting of meteorological data; the control of power supply and gate movement; the inspection of welds, corrosion, seals, lubrication; coping with vibrations, and with the deposits of trash and debris. Thus, gate management is a complex multi-tasking effort. The book treats all these subjects in a meticulous and concise manner.

The profession is fortunate that the author decided to spare no efforts in preparing this greatly revised second English edition. I hope the book will be widely distributed and read. It should increase awareness about the continuously topical issue of gate safety.

The book also comes at an opportune moment as our profession is now exposed to an increasing conflict of interest between an engineer's and investor's attitude as to how to set priorities with respect to safety. This conflict is understandable under the circumstances of financial constraints but it certainly is not conducive to an unbiased decision on safety issues. Also in this respect, the book provides valuable guidance.

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Consulting Engineer
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Acknowledgements

This second edition retains coverage from the original edition on the technical bases for designing hydraulic gates. In response to many requests in the last years for enlargement of the book, two new chapters have been added on the arrangement and design of intake gates and trashracks.

Some chapters have been brought up to date, mainly on topics such as gate lateral guiding (Chapter 6); seal deformation under load (Chapter 9); schematic oil-hydraulic diagrams for gate hoists (Chapter 11); and metallic seal leakage, double-sealing gates and design considerations for seals of high-head segment gates (Chapter 13).

Current practices in the selection of intake gates and hoists are reviewed in Chapter 16. Increased competitiveness in the construction of dams and power plants has led an intense effort to reduce the costs of hydromechanical equipment. Nevertheless, the author emphasizes that, in the selection and arrangement of the equipment, safety aspects should take priority over capital costs. Methods for filling the penstock are evaluated. The arrangement of guard gates for bulb and Kaplan turbines is discussed as well as the need of stoplogs for maintenance and inspection of the guard gate embedded parts, mainly the wheel tracks and the seal seat frame.

Chapter 17 deals with the selection and design of intake trashracks. Special attention is given to rack bar spacing, flow velocity, head losses and flow-induced vibrations. Types and characteristics of rack-cleaning machines are discussed. As a result of a series of reported failures of trashracks sized according to recommended design standards, more rigid calculation assumptions, design parameters and manufacturing procedures are presented.

The author wishes to express his special gratitude to the engineer John Cadman, who also contributed to the first edition of this book, for the invaluable help in proof-reading the texts added to this edition. Acknowledgement is also addressed to Bruno and Vincenzo de Luca, for their dedication in preparing the illustrations for the new chapters 16 and 17.

The author could not fail to renew his thanks to all gate manufacturers and organisations which supplied a large share of the photographs, drawings and graphics for the first edition and were reused here, as well as to Bosch-Rexroth, Federal-Mogul Deva, Ruhfus, KGAL, Obermeyer, Kunz, Rubberart, and Bardella, who kindly provided additional material for this edition.

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Chapter 1

Introduction

1.1 HISTORY AND DEVELOPMENT

The construction of hydraulic gates was closely related with the development of irrigation, water 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. As a natural evolution, '*movable dams*' were built. These movable dams could be removed from their normal position to provide passage for excess water, thus permitting greater safety and flexibility in the operation of hydraulic works.

The first canals for transportation of goods and drainage of floodwaters were built in China. Originally, the Chinese solved the problem of fluvial transportation in the region of river rapids by building dikes with slopes on the banks of the canal. The boats were then manually hoisted up and down the slope. These operations, however, were both time- and power-consuming. Around the year 983, the Chinese discovered that by constructing two dams a certain distance apart, the boats could enter the '*pool*' created between them and the water level could be slowly increased or decreased. The earliest dams had wood or stone piers on each side of the canal. Vertical grooves were cut into opposite sides of the banks and tree trunks were fitted horizontally into the grooves, which held the water at the highest level. Ropes were used to lift the trunks. Later, the trunks were linked, forming an integral barrier that could be lifted or lowered like a guillotine blade.

The development of gates in The Netherlands followed a pattern similar to that of China. At the end of the 14th century, locks were very common there. The gates, still of the guillotine type, were provided with lead counterweights and equipped with drains, which permitted emptying gradually the lock chambers [1].

In 1795, the Little Falls canal was completed, making it the first canal with locks in America. The design of wooden gates for the Little Falls locks was unusual. Two wood swinging gates were placed at each end of a lock. Instead of closing to a flat plane, the gates closed to form an angle pointing upstream, facing the current. Water pressure thus locked them together. Near the base of the large gates were sluice jacks or small cast iron plates, which pivoted vertically, allowing water to enter or leave a lock. The same arrangement, using miter gates, was used for the Great Falls locks. Butterfly valves, pivoting horizontally at mid-height were used instead of sluice jacks to empty and fill the lock chambers [2].

The first metal gates appeared around 1830. Around the turn of the century, various inventions occurred as well as a great development of the existing types, furthered by the challenge of the need to build ever-larger gates.

Filipo Maria Visconti designed the first pound lock in 1439. This was at Vareno, near Milan, Italy, to improve navigation for the transportation of granite blocks used in the construction of Milan's Duomo. In 1638, a pound lock was built at the Briare canal in France [3]. The first drawing of a pound lock is dated 1497 (see Figure 1.1). This illustration already exhibits the main features of a modern lock, with gates pivoted instead of working vertically. The enlargement in the center permitted the passage of more boats at the same time.

On the chamber walls anchorage eyes were installed to which the crafts could be connected by ropes to prevent their displacement during the chamber filling and emptying, operations that certainly caused great turbulence. One of the lock gates is a miter gate similar to those used nowadays. Filling and emptying were carried out through small openings provided with gates for their closure. This system is still used

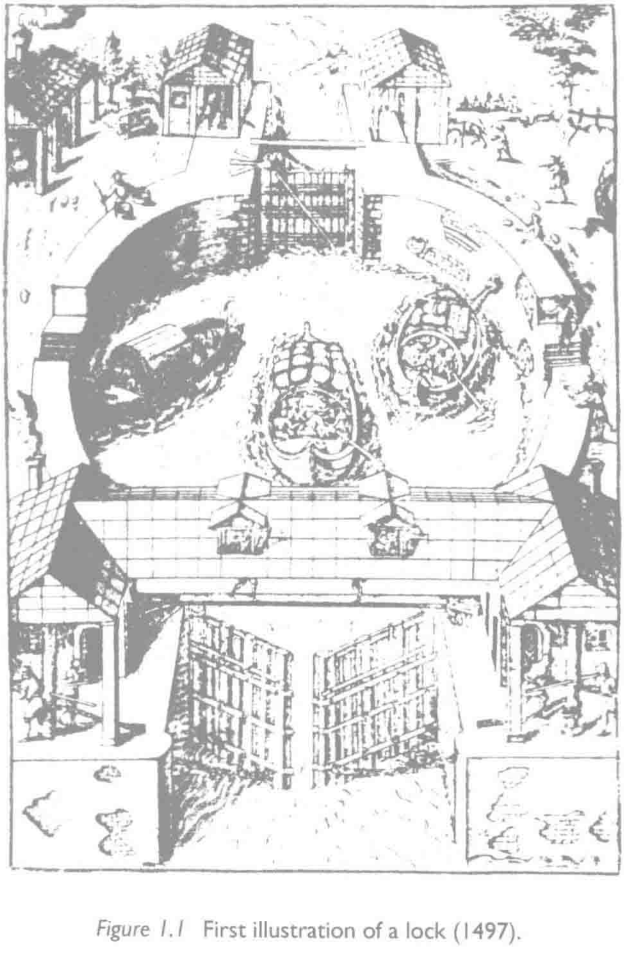

Figure 1.1 First illustration of a lock (1497).

at the present time in small locks [4]. Miter gates, designed with cast iron structure and steel plate shielding, were used as far back as 1828, on the Nivernais canal in France. A metallic miter gate was used in the Charenton lock, France, in 1864; this gate was 7.8 m wide by 7.76 m high [5].

The invention of the pound lock is credited to Leonardo da Vinci (1452–1519). This is not true, although da Vinci did bring many innovations to it.

The oldest known application of a segment gate was in 1853, on the Seine River, in Paris, where four gates 8.75 m wide by 1.0 m high were installed. These were designed by the French engineer Poirée [6], who is also the inventor of the needle dam first used in 1834 on the Yonne River, in France [7]. Other early applications occurred on the Nile River delta, ca. 1860, where 132 segment gates 6 m wide by 5.1 m high were built by the French engineer Mougel Bey for the Rosetta and Damietta dams. The gate arms were subjected to traction. At the time they were called '*cylindrical gates with radiuses subjected to traction*'. According to Wegmann, the original gates for closing the openings between the piers were shaped as the arc of a circle, supported at either end by iron rods radiating from the center of the arc, where they were attached to massive iron collars, working round cast-iron pivots embedded in the masonry of the piers. These gates were to be lowered by their own weight and to be raised by compressed air pumped into the hollow ribs, but they could not be operated successfully and were replaced after 1884 by wrought-iron gates provided with rollers sliding in cast-iron grooves fixed in the piers, according to F.M. Stoney's patent. Powerful crab winches (two for each dam) traveling on continuous rails served to lower or raise the gates [8]. In 1910 a patent of a reverse segment gate was assigned in the USA to L.F. Harza.

Around 1870 in the USA parallel inventions of the segment gate occurred [9]. Rehbock and Hilgard, together with A.O. Powell, give the name of the inventor as T. Parker who, however, presumably sold his ideas to Jeremiah Burnham Tainter,

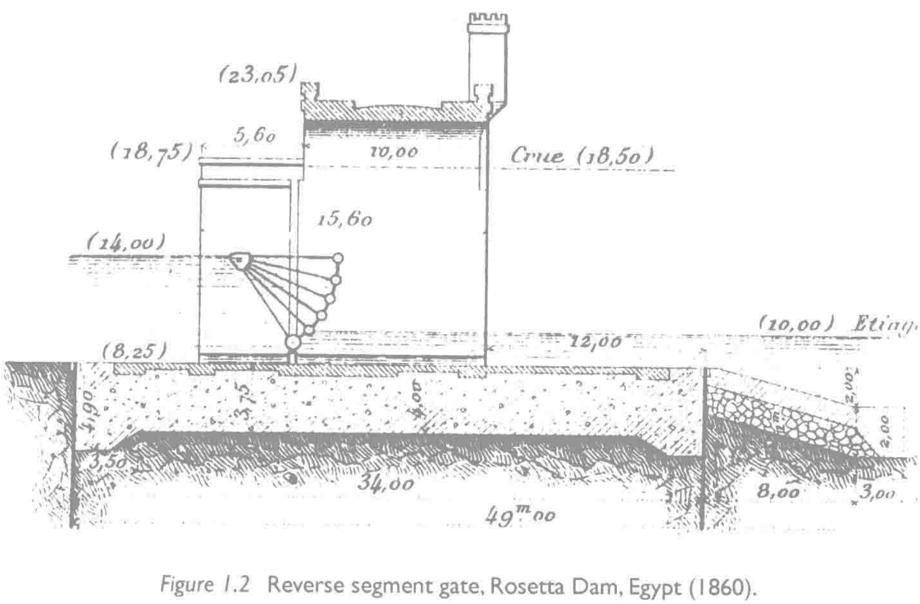

Figure 1.2 Reverse segment gate, Rosetta Dam, Egypt (1860).

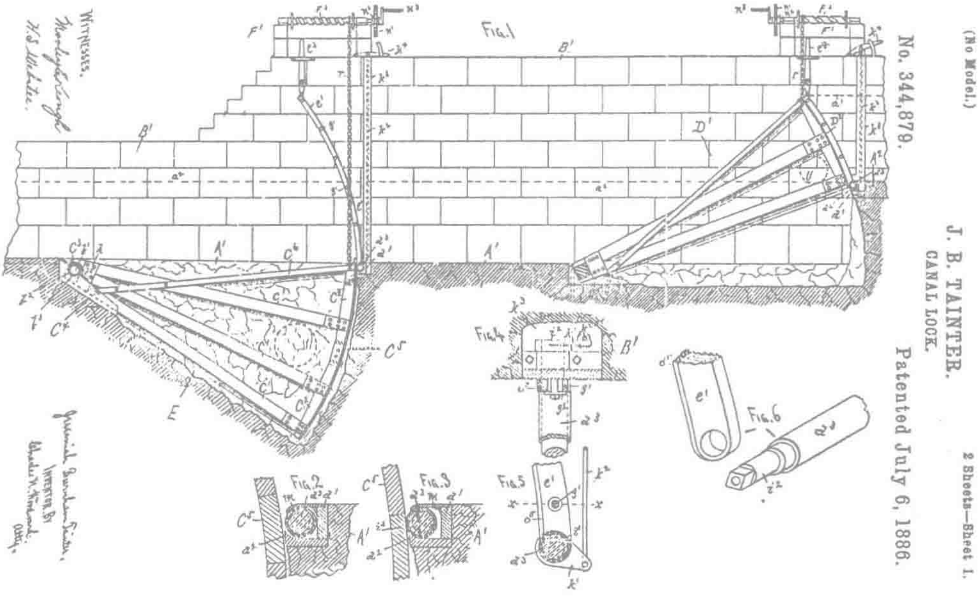

Figure 1.3 Segment gate, Tainter's patent (1886).

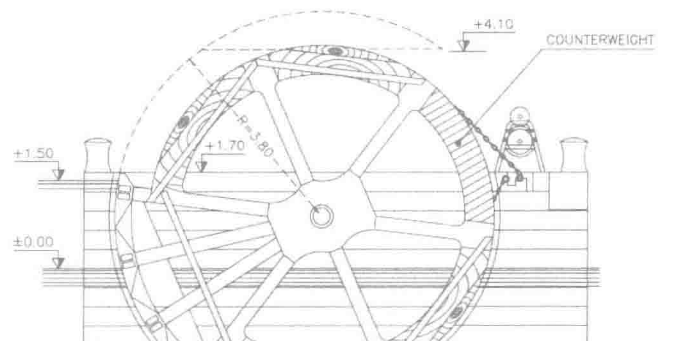

Figure 1.4 Segment gate with counterweights, Lez River, France (1888).

from Menomonee, Wisconsin. In 1886 he patented it in his name, receiving from the U.S. Patent Office the number 344879. The gate had three radial arms and wood construction. It was driven by chains installed upstream of the skin plate. The gates would be installed in tandem to serve as lock gates and also for filling and emptying the lock chamber.

Figure 1.4 shows a segment gate with counterweights, built in 1888, at the Lez River, south of France.

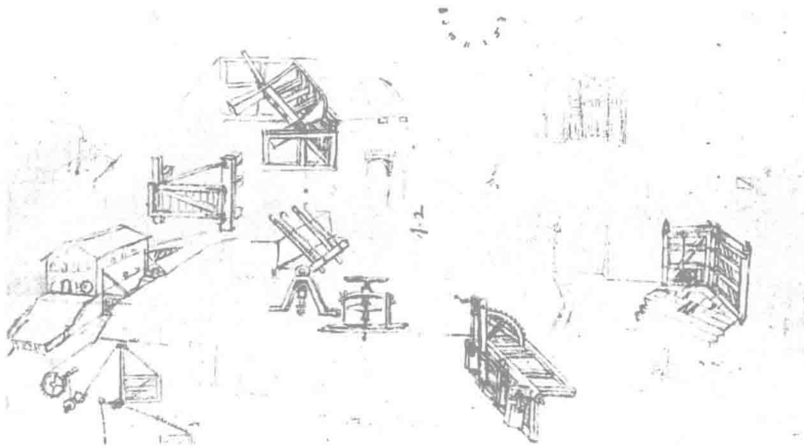

Figure 1.5 Various types of gates, by Leonardo da Vinci (circa 1490). Property of the Ambrosian Library.

In Germany, the first reports of segment gates date from 1894/1895 and refer to the installation of a gate with a span of 12 m and 1.87 m high in the Werderschen Mühlegraben, Berlin. Later on, in 1903, another gate was built on the Landwehr canal, with a 5.56 m span and 1.6 m high. Both had arms subjected to compression. In 1895, reports were published in the USA describing the use of segment ('*Tainter*') gates in the Illinois-Mississippi channel.

The segment gates were initially used in the USA for flow control in conduits and used for the first time in lock aqueducts in the construction of the New York barge canal, in 1905. Reverse segment gates were used again in 1953, at the Oberpeichning dam, on the Lech River, Germany. They were 16 m wide and 8.25 m high, and had a 2.15 m high flap gate at the top. Because of the highly reliable performance of these gates, about 28 others were built up to 1976 in the Bavaria region, Germany [4].

Notwithstanding the efforts developed in the 19th century by the various inventors of the segment gate, it is remarkable that all were preceded by the great genius of the Renaissance, Leonardo da Vinci. In his studies on hydraulics, around 1490, da Vinci already registered that type of gate. In Figure 1.5, one of his studies in Codex Atlantis, can be found: miter gate (right); top-hinged flap gate (below, right); plain gate with vertical hinges (left); and a segment gate (top, center). This gate has radial arms extending beyond the trunnions. The arms act as counterweights, easing the manual operation of the gate by leverage. The gate shield is curved like the modern gates.

The much-emphasized advantage of the segment gate (the absence of slots in the piers) does not appear in the first reports because then they were often used. In 1914, H. Engels said: '*The segment gates present advantages over other gate types up to 12 m of span*' [10]. H. Kulka, in 1928, was even more optimistic: '*The introduction of forces in the piers does not cause problems, even on large gates. There is no problem in the construction either of the trunnions or of the piers. Segment gates may be used for any practical dimension*' [11].

In fact, some segment gates have been built with remarkable dimensions:

Dam	*River*	*Year*	*Span (m)*	*Height (m)*
Barthelm	Oder	1920	40	3.0
Ladenburg	Neckar	1927	36	5.5
Münster	Neckar	1927	23	7.4
Donzère-Mondragon	Rhone	1948	45	9.0
Haringvliet	Rhine-Mosel-Scheld delta	1967	56.5	10.5
Vilyu		1967	40	14.0
Stör	Stör	1975	43	13.0
Altenwört	Danube	1976	24	15.5
Itaipu	Paraná	1982	20	21.3

Double-leaf gates originated in Europe, and are found in Japan. Double-leaf metal gates, 5 m wide by 5 m high, were used to close the 111 arches of the Assiout dam, Egypt, in 1902 [12].

In 1908, ten double fixed-wheel gates were installed on the Augst-Wyhlen dam, on the Rhine River, Switzerland, each gate being 17.5 m wide and 9 m high [13]. The modern double fixed-wheel gate of the hook type was developed by M.A.N. and installed for the first time on the Reckingen dam, Switzerland, in 1930.

Similar to the double-leaf fixed-wheel hook type gate, double segment gates were developed. However, few installations were built, all in Switzerland. These are the three of the Rupperswill-Auenstein dam, on the Aare River, in 1943, with a 22 m span and 8 m high and the two at the Brunau dam, on the Sihl River, in 1969, with a 20 m span and 5.5 m height [14].

The sector gate was invented in the USA by C.L. Cooley, and used for the first time in 1907 in the Lockport dam on the Chicago drainage canal. Two gates were installed to regulate the flow in the canal and to carry off ice and floating debris. One had a 3.66 m span, and the other a 14.6 m span. In both gates the curvature radius of the skin plate was 7.92 m and the height 5.79 m. The pivot consisted of lengths of 100 mm rods, supported by cast steel brackets on the back wall [8].

In Europe, the first application of the sector gate was in 1911, when two gates were installed on the Weser dam, near Hemelingen, Germany, with a 54 m span and 4.6 m height. According to H. Ackermann, during the early studies of that dam, the use of rolling, fixed-wheel, segment and flap gates was also studied. The choice of the type, however, favored the sector gate because of the need for a submersible gate. At that time, submersible gates of the roller, fixed-wheel and segment types were already known, but had not yet been tested in practice. The design of the Weser dam gates is similar to that of Lockport [15]. In 1924 three sector gates were installed in Brazil at the Ilha dos Pombos Dam, on the Paraiba River, with a 45 m span and a height 7.4 m. These gates so far hold the record of the largest impounding area (333 m^2) for those of its type [16].

Max Carstanjen, chief engineer of the Gustavsburg Bridge Works (M.A.N.), Germany, invented the roller gate in 1898. Its first application was on the Sau River. The gate had an 18 m span and a height of 4.14 m. To reduce the buoyancy effect, its central body had a pear-shaped cross-section, while the ends were cylindrical. In 1903, another gate, 35 m wide by 2 m high, was installed in the same region, on the diversion canal of the Main River; this operated for about 60 years [17].