# The Evolution of Operating Machines for Ancient and Modern Huai'an Sluices

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**Abstract.** Based on a retrospective analysis of the operating machines employed in ancient Huai'an continuous sluices system, as well as those utilized in the modern Huai'an regulation and canalization system, this article provides a comprehensive exposition of the intricate details pertaining to the Yangzhuang Regulator, particularly focusing on its operating machines. The objective is to elucidate how Chinese capacity for regulating the Huai River has been enhanced within the context of evolving patterns of river regulation and through technology transfer from Western hydraulic practices.

**Keywords:** Huai'an sluices · Yangzhuang regulator · Operating machines

## 1 Introduction

Since ancient times, the sluices and their operating machines have played a crucial role in Huai'an, because this city has been the intersection of numerous water bodies such as Huaiyang Canal, Huai River and Yellow River. During the Early Ming to Middle Qing Dynasty, hydraulic officers primarily focused on ensuring smooth tribute rice transportation from south to north through the implementation of intricate continuous sluices at Qingkou and Qingjiangpu. Continuous sluices were multiple sluices built in the canal [1], known as 'Zhahe' in ancient Chinese. These measures aimed to regulate sedimentation in the Yellow River while enhancing the independence of Huaiyang Canal; However, the sluices operating machines remained relatively primitive during this period. In late Qing Dynasty, following a significant change in the course of the Yellow River in AD 1855, there was a shift in Huai River regulation schemes from constructing sluices to dredging sea-access routes. It wasn't until the Republic of China era that advancements were made towards improving technology related to sluice operating machines.

During the Republic of China, early Chinese hydraulic professionals established hydraulic engineering schools and water conservancy institutions in Jiangsu Province, indicating the transfer of modern Western hydraulic technology to the Huai River region. These professionals formulated comprehensive regulation and canalization plans; However, their efforts yielded limited results. Notably, in 1935–1937, the construction of Yangzhuang Regulator on the sea-access route marked a significant milestone as it became the first sluice for regulation and canalization built with modern operating machines in Huai'an.


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## 2 Ancient Huai'an Continuous Sluices with Primitive Operating Machines

In ancient times, hydraulic officers in Huai'an organized the construction of continuous sluices in Qing Jiangpu and Qingkou to mitigate flood hazards, particularly along the Huaiyang Canal. However, over time, these machines remained relatively primitive in their structure. Conversely, the system of continuous sluices gradually evolved into a more intricate and sophisticated network.

### 2.1 Ancient Huai'an Continuous Sluices System

According to the literature review, the term Xuanmen referring to sluices equipped with windlasses were initially observed in a continuous sluice system called Sha Canal in Huai'an [2]. This canal was excavated by Qiao Weiyue in AD 984 near the southern bank of the Huai River. The purpose of installing Xuanmen was to mitigate the risks associated with sailing on the treacherous Huai River by allowing water accumulation until reaching desired levels. During the Ming and Qing dynasties, this sluice system underwent further refinement based on its Song Dynasty predecessor [1]. In AD 1415, Chen Xuan, a native hydraulic officer, dredged anew the Sha Canal and renamed it Qingjiangpu. At that time, Qingjiangpu Canal served as a crucial channel connecting Huaiyang Canal and Huai River while enhancing independence from Yellow River influences. Alongside Qingjiangpu Canal, five distinct sluices named Xinzhuang, Fuxing, Qingjiang, Yifeng and Ban respectively were constructed for efficient regulation of water flow. Upon boat arrival at these locations, sequential operation of these five sluices ensured smooth navigation through coordinated opening and closing.

In Southern Song Dynasty, the Yellow River changed its course and claiming the lower reach of Huai River. This resulted in gradual sedimentation, leading to the formation of Hongze Lake in the western region. Consequently, Huai'an faced an increased risk of flooding [1]. To address this issue, a system of continuous sluices for flood-discharge and navigation was established near Hongze Lake. During the 16th century, Panjixun firstly summarized the designing and building experiences of flood-discharging sluices and weirs within the levee system near Hongze Lake. In subsequent years during Qing Dynasty, sediments from the Yellow River accumulated in its riverbed causing a confluence with both Huai River and Huaiyang Canal known as Qingkou. Extensive human resources and efforts were dedicated to constructing continuous sluices at this location. Among these projects, three coupled sluices - Huiji, Tongji, Fuxing - were particularly noteworthy as they ensured smooth navigation between Huaiyang Canal and Middle Canal.

### 2.2 The Structure of Operating Machines for Ancient Huai'an Sluices

The operating machines employed in ancient Chinese sluices served to effectively distribute weight and minimize labor during the installation and removal of gate planks. Based on extensive literature research and recent archaeological discoveries [3–5], it can be inferred that the operating machines utilized in ancient Huai'an sluices adhered to a typical structure (Fig. 1). These sluice gates, known as 'Zha', primarily consisted of two opposing vertical grooves spanning the waterway, with a series of interconnected gate planks positioned within these grooves from top to bottom [2]. The primary operating machines comprised stone crane arms, known as Jiaoguanshi, strategically positioned on each bank and equipped with windlasses or pulleys called Qianjin. Ropes were securely attached to both ends of the planks through these windlasses or pulleys, facilitating the elevation of upper planks or the smooth passage of boats. This ingenious system was occasionally enhanced by fastening all the planks together to create a continuous surface, which could then be raised or lowered in grooves using counterweights affixed to the cable ends. Presently, remnants of stone crane arms can still be observed along the Grand Canal (Fig. 2).

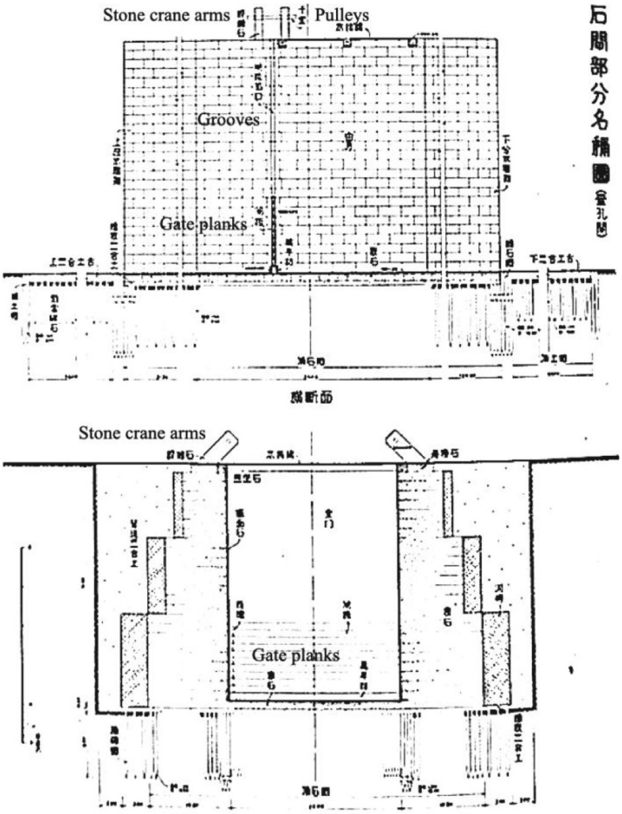


**Fig. 1.** The typical forms of ancient Chinese sluices on Grand Canal [5]

However, ancient Huai'an people did not develop an accurate and automatic sluice operating machine. Instead, they opted for a more complex continuous sluices system with simpler technical details. On one hand, branch channel called Yue River was excavated alongside the main canal as an emergency measure when the flow was too high or too low. On the other hand, the gates of flood - discharging sluices were removed in the

**Fig. 2.** Stone crane arm at Gaobeidian. Photoed at Gaobeidian by Yingjie Chu

16th century due to conflicts of interest among local stakeholders and inadequate central management, which hindered further progress in hydraulic technology [6].

## 3 Operating Machines for Modern Huai'an Sluices

The introduction of modern sluice operating machines to China was a result of the introduction of western regulation and canalization systems, which took approximately twenty years. This process began with the establishment of Hehai Engineering Institute in AD 1915 and Jiangsu Grand Canal Improvement Board in AD 1920, both of which contributed to the accumulation of modern technological capabilities for local hydraulic engineering and transformed the pattern of Huai River regulation into comprehensive plans. Yangzhuang was a key location as it intersected Salt Canal, Middle Canal, and Old Yellow River Channel. The process culminated with Huai River Conservancy Commission (HRCC) constructing sluices according to the Huai River Engineering Plan - marking the first time that modern operating machines were used in this region. Among these sluices, Yangzhuang Regulator serves as an appropriate case study for examining how native engineers applied their hydraulic knowledge within the context of western hydraulic technology transfer.

### 3.1 The Earlier Accumulation of Technological Capabilities in Huai River Region

In AD 1916, Li Yizhi compiled a textbook titled 'Hydraulic Engineering [7]' for Hehai Engineering Institute, through which he provided a concise and systematic introduction to European sluice operating machines, particularly those from Germany, to Jiangsu [8]. This knowledge was incorporated into Sect. 3 Part 3 of Li Yizhi's book, where he elaborated on the various types of movable dams used in canalization engineering.

Movable dams were designed to be adjustable according to need; they ensured sufficient water depth for navigation during dry seasons and could be opened for flood discharge during periods of flooding. Often accompanied by a lock system facilitating boat passage, these movable dams encompassed different categories such as gate dam, flash boards dam, needle dam, drum weir, rolling dam, among others. The gate dam and flash boards dam were analogous to contemporary sluices, resembling the Chinese sluice gates in both their machinery structure and functioning (Fig. 3). Li Yizhi specifically noted various types of operating machines for the gate dam, including lifting levers, chain & drum systems, screw rods & hand wheels, and operation gearings. The latter was utilized for raising large gates and featured a more intricate machine than the former options. Figure 4 demonstrated an efficient method for hoisting sizable gates whereby force was transmitted through a crank handle to the rack before being transferred to the worm gear.

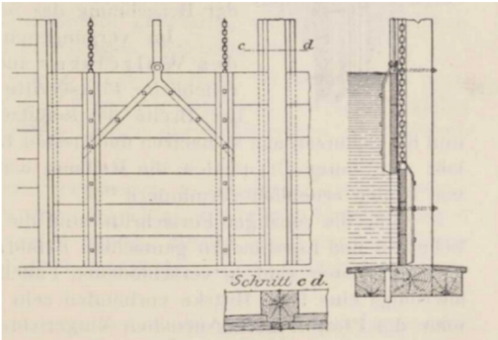


**Fig. 3.** The structure of modern gate dam [8]

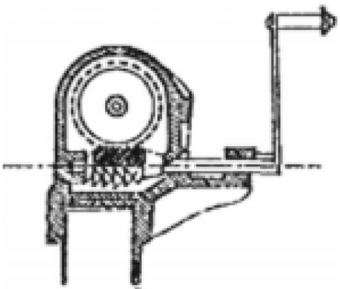

**Fig. 4.** Operating machine for gate dam in Li Yizhi's book [7]

In AD 1920, Zhang Jian established the Jiangsu Grand Canal Improvement Board, which made plans for the construction and reconstruction of sluices near Yangzhuang with modern operating machines. However, due to the technical limitations of local residents, many construction projects were not implemented as intended, resulting in reconstructions that adhered to traditional structures.

In the A Huai River Engineering Plan published in AD 1920 [9], the board proposed the construction of a movable dam for the first time in Yangzhuang. Although explicit technical details were not provided, they plotted the structure as a needle type (Fig. 5), wherein individual needles could be manually added or removed to regulate river flow and form a sluice. Additionally, the frame bent structure had the capability to be raised or lowered. Ultimately, this proposal remained at the design stage; however, the plot demonstrated an endeavor to introduce a modern canalization system to Huai'an through through collaborative relationship of movable dam and ship lock.

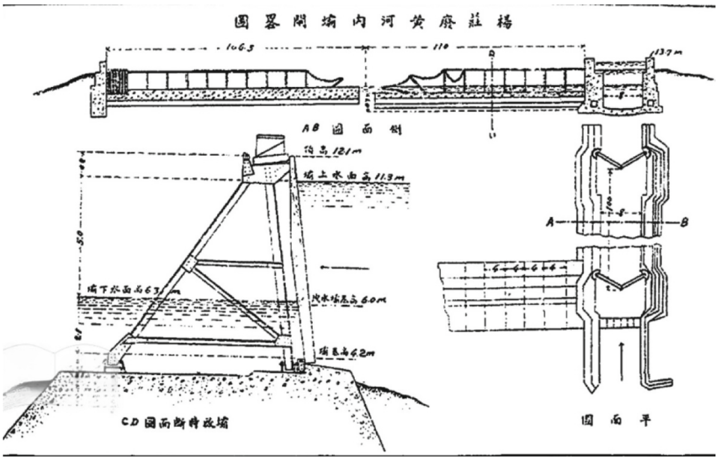

**Fig. 5.** The design of Yangzhuang movable dam by Zhangjian [9]

Later, the board appointed Emory Wilson Lane, an American engineer, as the chief engineer. He devised a series of regulatory plans that involved constructing modern sluices with operating machines around Huai'an [10]. In 1921, he was assigned to oversee the reconstruction work of Shuangjin Sluice. The original design for the machine in the Shuangjin Sluice Reconstruction Plan [11] utilized ancient lifting arms due to financial constraints; however, there were still modifications made in civil engineering. The process of designing these lifting arms transitioned from being planless to becoming graphical (Fig. 6). Additionally, instead of using traditional craftsmanship, concrete with small broken stones was employed as the material for these lifting arms according to the graph presented.

### 3.2 The Design and Construction of Yangzhuang Regulator by HRCC

In the 1930s, recognizing the gravity of hydraulic issues in Huai'an, the National Economic Council of the Republic of China entrusted HRCC with the responsibility of identifying a practical solution [13]. Drawing upon previous research findings, HRCC formulated comprehensive plans known as the Huai River Engineering Plan [14] and Huai River Sea Access Project [15], respectively in AD 1931 and AD 1933. The surveying and planning process for these projects was carried out by local engineers with assistance from Western hydraulic consultants, thereby providing valuable reference data for machine design.

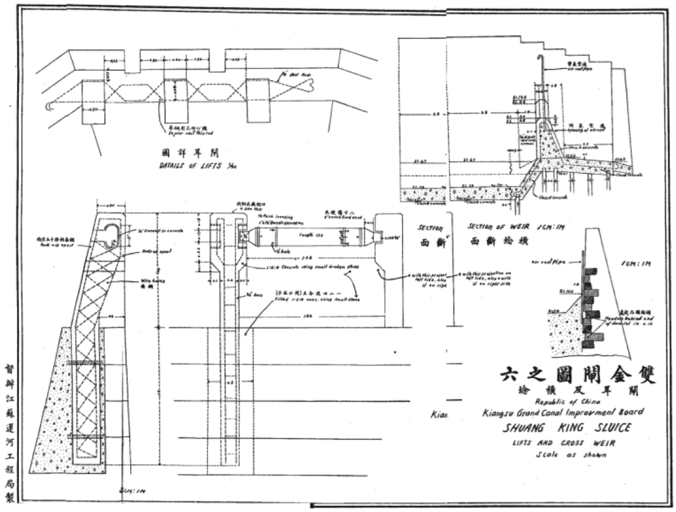


**Fig. 6.** Shuangjin Sluice lifts and cross weir [12]

In the comprehensive plans, the implementation of building regulators (movable dams) at specific locations was considered a practical solution for flood-discharging and facilitating smooth navigation. Prior to 1937, only one regulator, namely Yangzhuang Regulator, had been successfully accomplished. Historically, there were two routes for regulating the Huai River: the Yangtze River Route and the Sea Access Route. The Huai River Engineering Plan primarily focused on elaborating the Yangtze River Route, leading to the initial design of Yangzhuang Regulator as part of a canalization system. Although it emphasized the cooperative relationship between locks and sluices in order to effectively canalize the river, technical details were not extensively discussed in this context. Subsequently, the HRCC opted to regulate the Huai River through both of the two proposed routes and developed a subsidiary plan for Sea Access Route in 1933. The Sea Access Route was designed to divert floodwater through Zhangfu River and Old Yellow River Channel towards the sea, thereby preventing inundation in the area between the lake and the sea. The subsidiary plan determined the site for the Yangzhuang regulator, situated upstream of the cut-off section of the old Yellow River channel, with the upstream section of Yangzhuang connected to the Middle Canal and Salt Canal (Fig. 7). In that case, the cargo boats from Huai'an could go directly through Inner Grand Canal into Middle Canal and Salt Canal without making a detour through Qingkou. The subsidiary plan also provided explicit water level and flow rate reference data for the regulator designing [15].

In 1935, the HRCC made the decision to use Stoney type Regulator sluices. This type of sluice-gate moved in vertical grooves in masonry piers on trains of rollers and was adapted for closing large openings in movable dams. The integrated design process was successfully carried out by the Engineering Bureau and Yangzhuang Regulator Engineering Bureau of HRCC. Between June AD 1935 and June AD 1936, these two bureaus meticulously developed a general Plan & elevation, foundation plan, details

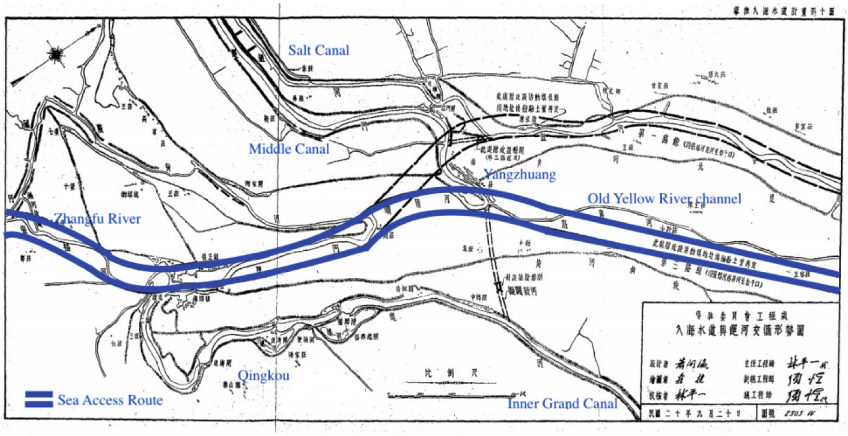


**Fig. 7.** The plan of Sea Access Route [15]

of pier construction, as well as details of construction structures [16], demonstrating that native engineers possessed a grasp of relevant civil engineering and mechanical principles.

The operating machines of sluice gates were primarily designed and fabricated by Messrs. Glenfield & Kennedy, a renowned manufacturer of such gates during that era, based in Kilmarnock, Scotland. They were entrusted with the responsibility of constructing all regulator sluice gates for the Huai River Engineering Plan, including those located in Yangzhuang and Sanhe among others. The contract for the construction of the Yangzhuang gates was signed on October 15th, 1935 between HRCC and Messrs. Arnhold & Co Ltd. Who acted as agents for Glenfield & Kennedy. As per the agreement and specifications provided by HRCC [17], Glenfield & Kennedy supplied all necessary manpower, fabricating machinery, and materials required for this project. The components manufactured by Glenfield & Kennedy (Fig. 8.) were then shipped to China where they were reassembled by local workers from Huai'an under their supervision. Additionally, China Car & Foundry Co Ltd also contributed to fabricating certain parts involved in this endeavor. To gain insights into fabrication details as part of his training program at the company [18], assistant engineer Sun Shixiong was sent by HRCC to investigate these aspects.

### 3.3 The Technical Details and Sources of Operating Machines

The Yangzhuang Regulator comprised of five Stoney sluices (Fig. 9). Based on the contract [17] and archaeological evidence, the operating machines of these sluices can be classified into three main components: rollers and roller paths, suspension machineries, and operating gears. Table 1 illustrates the division of labor between Glenfield & Kennedy and China Car & Foundry Co., Ltd for fabricating these three parts. Figure 10 demonstrates the collaborative relationship among these operating machines. The force was transmitted through a crank handle to gears that operated on shafts, ultimately terminating in winding drums (Fig. 11) which supported the suspension machineries.

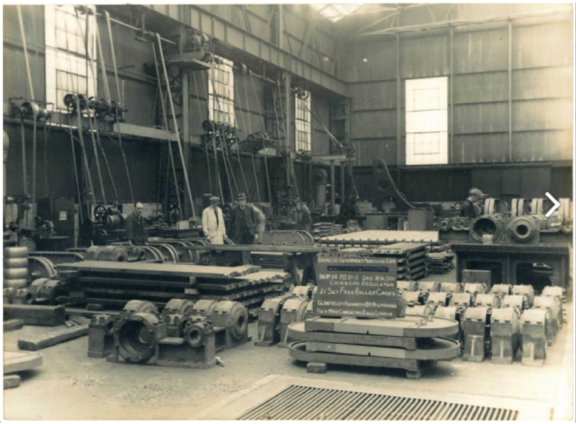

**Fig. 8.** Mechanical parts for regulators provided by Glenfield & Kennedy [19]

Galvanized steel wire ropes were used to connect the gate with its counterbalance via winding drums, while rollers and roller paths facilitated smooth upward and downward movements of the gates.

**Fig. 9.** Yangzhuang Regulator nowadays. Photoed at Yanzhuang Regulator by Yingjie Chu

The precision and mechanization of the system were primarily attained through the utilization of operating gears, comprising a dual-speed central headstock encompassing spur reductions, shafting, and self-aligning couplings. The reductions were set for changing the ratio, 2 men can easily lift and lower the gates under full unbalanced head at a rate of 1 ft. Per minute on the slow gear, and 3 to 4 ft. per minute on the quick gear. Based on the information presented in Fig. 10 and Fig. 11, it can be inferred that the headstock employed a conventional single-reduction gear unit, as depicted in Fig. 12.

**Table 1.** Division of labour for the machinery between Glenfield & Kennedy and China Car & Foundry [17]

| Name | Division of labour | | |
|---|---|---|---|
| | Rollers and roller paths | Suspension machineries | Operating gears |
| Messrs. Glenfield & Kennedy | roller trains, suspension chains, brackets, rocking paths, side staunching bars, necessary bolts, iron roller grooves, | steel wire hoisting ropes, cast iron suspension pulleys | cast iron winding drums, shafting, self-aligning couplings, two speed central headstock enclosing spur reductions, brakes, lock, indicator etc |
| China Car & Foundry Co.,Ltd | mild steel sluice gates structural parts | counterbalance guide channels | steel hoods for covering operating gear drum |

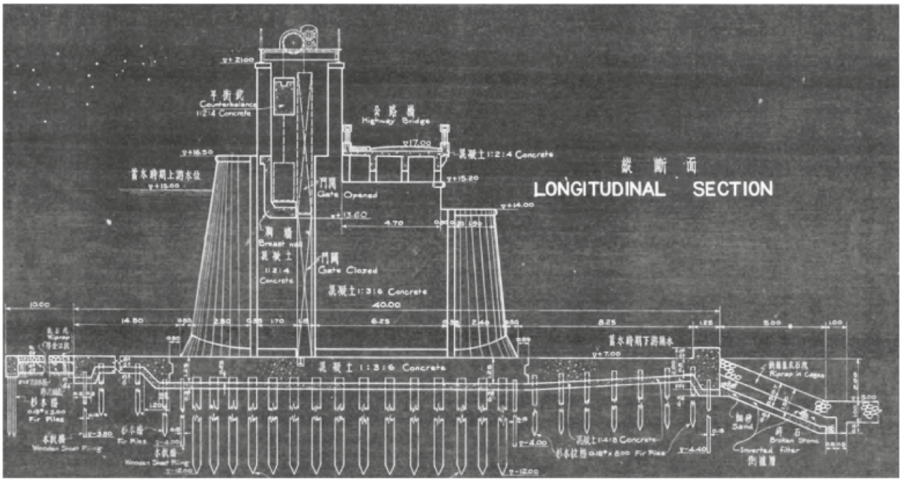


**Fig. 10.** The longitudinal Section of Yangzhuang Regulator [16]

The technical expertise in fabricating Yangzhuang Regulator operating machines was derived from Glenfield & Kennedy's extensive global experience in constructing hydraulic equipment, which was based on the company's design and manufacturing capabilities accumulated since the 19th century.

The founders of the company, Thomas Kennedy Senior and Junior, acquired design capabilities for sluices operating machines [21, 22]. Thomas Kennedy Senior, a skilled watch and clock maker, obtained a patent for the Kennedy Water Meter - a machine designed to measure water quantity. Subsequently, he established both the Kennedy Patent Water Meter Co Ltd and Glenfield Co Ltd in the 1960s. Mr. Thomas Kennedy

**Fig. 11.** The general construction of the gear. Photoed at Yanzhuang Regulator by Yingjie Chu

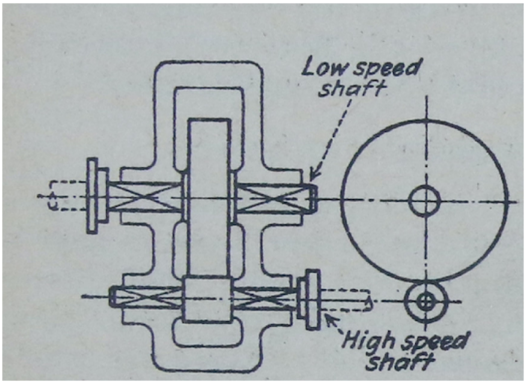


**Fig. 12.** The single-reduction gear unit [20]

Junior joined the company's workforce in 1867 and over his remarkable 46-year tenure demonstrated exceptional technical prowess and organizational skills. He played an instrumental role in successfully executing numerous significant contracts related to waterworks supply, sewerage systems, pumping stations, as well as hydraulic plants for municipalities both domestically and internationally.

In the early 1900s, two formal companies merged to form Glenfield and Kennedy Co Ltd, thereby acquiring a manufacturing capability of significant scale [21, 22]. The company underwent substantial growth, transitioning from a small enterprise with approximately fifty employees to a prominent establishment that employed over 1800 individuals during normal operations. It possessed various facilities including foundries, dressing shops, smithy, and the machine department. Serving as the central hub for all operations, the machine department encompassed the light machine shop, heavy machine shop, testing shop, and brass-finishing shop. In 1919, an esteemed research and development department was established which greatly contributed to the rapid advancement of novel lines of production [23].

Sluice valves have been the primary products of Glenfield & Kennedy for an extensive period, dating back to early times. The machines used for sluices closely followed the practice developed for sluice valves. The core technology of Regulator operating machines was the operating gear. A publication by the company in 1916 [24] documented various types of sluice valves and their fittings, including those with anti-friction rollers, headstocks designed specifically for sluice valves, and gearing systems employed to operate the valves. Figure 13 depicted a spur wheel gearing system utilized for working large valves, featuring a bracket cast on the stuffing box and gland bushed with gunmetal material. During the 1920s–1930s, Glenfield & Kennedy focused their efforts on producing sluices tailored for open channels and culverts [25]. These products garnered significant interest from irrigation and river control engineers worldwide, particularly in India where they supplied practically all major regulators associated with storage reservoirs and river regulation [13]. Figure 14 illustrates a free roller gate constructed in India in 1932 by Glenfield & Kennedy, which exhibited an integrated design akin to the Yangzhuang Regulator. Notably, this firm placed significant emphasis on patent applications, thereby contributing to advancements in all sorts of components. Figure 15 showcases a balancing structure for sluice-gates of the free-roller type. These gates were operated using a rope that passed over a helically-grooved double coned pulley and connected to a balance-weight. The arrangement ensured that when the gate was closed, the section of the rope attached to the weight led from a groove with greater radius compared to that from which the section attached to the gate originated. Conversely, when the gate was open, this relationship reversed [26].

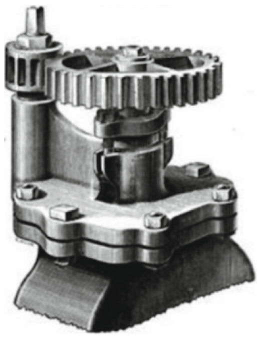

**Fig. 13.** Spur wheel gearing for working large valves [24]

**Fig. 14.** A free roller gate built in India in 1932 by Glenfield & Kennedy [25]

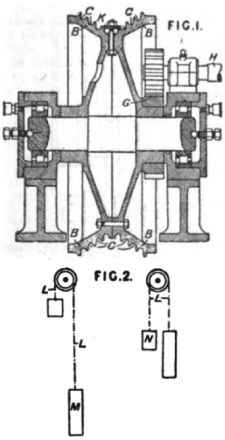


**Fig. 15.** A balancing structure for sluice-gates of the free-roller type [26]

## 4 Conclusion

The evolution of operating machines for ancient and modern Huai'an sluices reflects the divergent hydraulic technology routes taken by China and European countries during the 19th and 20th centuries, encompassing disparate building crafts, mechanical technologies, and hydraulic sciences. While the operating machines for ancient Huai'an sluices predominantly employed stones and woods as structural components - with detailed records of these materials' craftsmanship in Ming and Qing Dynasties - iron structural parts were rarely utilized. In contrast, cast iron emerged as a crucial material for structures in Europe during the 18th century; Smeaton incorporated it into gearing and other millwork in the 1750s [27], resulting in numerous metal structures that differed from those found in ancient Chinese designs - such as roller trains or cast iron winding drums used to regulate modern sluices. The precision of European mechanical technologies was a distinguishing feature that ancient Chinese sluice operating machines lacked. Thomas Kennedy Senior incorporated the intricate mechanics found in watches and clocks into water measurement, thereby instilling a pursuit for accurate measurements within the company's hydraulic productions, ranging from water meters to sluice indicators. Fluid mechanics served as the scientific foundation for constructing precise operating machines, with Thomas Kennedy's patent on water meters embracing the 'Venturi law' developed during the 18th century. This law enabled the measurement of flow rates in enclosed pipes and significantly expanded the company's business prospects throughout the 19th and 20th centuries.

The evolution of sluice operating machines in Huai'an was a gradual process influenced by the transfer of western hydraulic technology and changes in the regulation patterns of the Huai River. From a technical perspective, the presence of continuous sluices with simple operating machines in ancient Huai'an reflected a system-oriented approach to hydraulic planning but lacked sophistication in hydraulic machine design. In the 1910s-1920s, modern concepts of regulation and canalization were introduced to Huai'an's hydraulic industry through various plans; however, the implementation of building operating machines was not realized due to limitations imposed by project scale. In the 1930s, HRCC formulated ambitious plans for the regulation and canalization of the entire Huai River. Concurrently, hydraulic machinery producers such as Messrs. Glenfield & Kennedy actively sought business opportunities with irrigation and river control engineers worldwide. As a result, Yangzhuang Regulator emerged as the first successful regulator equipped with modern machines in Huai'an. From a geographical perspective, changes in the regulation pattern of the Huai River were influenced by both natural factors - such as Yellow River altering its course - and social factors - such as shifts in goods transported along the river in Huai'an. Given its strategic location at the intersection of Old Yellow River Channel, Salt Canal, and Middle Canal, Yangzhuang necessitated a precise and automated approach to ensure consistent water levels during dry seasons while preventing inundation during flood seasons. Leveraging Messrs. Glenfield & Kennedy's technical expertise, these operating machines effectively served multiple functions for regulating and canalizing the Huai River.

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