Technological evolution of crane ships in port construction

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ABSTRACT: Port construction work has characteristics that set it apart from other civil engineering works, as the majority of it is carried out at sea. For work at sea, crane ships are used to install caissons and erect bridge girders at sea. The history of the use of cranes in Japan began during the Meiji period, when a motorized crane ship was imported from Britain for the construction of Yokohama Port. There have been general summaries of crane ship technology, but there has been no summary that takes into account the division of eras and background. This article therefore summarizes the technological changes in crane ships in port construction work, and looks ahead to the next turning point.

1. RESEARCH OVERVIEW

(1) Introduction

A crane ship is a work ship that transports heavy objects from the manufacturing site and installs them on site, such as installing wave-breaking blocks and caissons, and erecting bridge girders at sea. In addition, they are often built as dual-purpose ships so that they can perform not only lifting work but also dredging work and pile driving work. Therefore, the number of ships owned is larger than other work ships, and in 2023, there are about 417 ships including dual-purpose ships.

The history of using cranes in Japan began when a motorized crane ship was imported from the UK for the construction of Yokohama Port in the Meiji era. During the postwar reconstruction process, crane ships were first used to raise sunken ships and other objects, and then enlarged, and they became widely used in port construction. In the subsequent high-growth period, due to the demand for larger scale offshore construction and shorter construction periods, a positive chain reaction state of fluctuation continued in which the enlargement of caissons encouraged the enlargement of crane ships, and as their performance improved, they began to be used for the collective erection of bridges. On the other hand, new structures and construction methods, such as new types of breakwaters and hybrid caissons, have been developed in light of improvements in the lifting capacity of crane ships and developments in positioning technology using GPS. In recent years, the incorporation of ICT technology has led to improvements in efficiency and productivity in various construction methods. This report aims to compile the technical evolution of crane ships in port construction and to pass on the technology. It also covers the latest technical information, organizes it, and compiles it into a document.

(2) Technological transition structure

The technological development of crane ships is closely related to the historical background, so I thought it would be easier to understand by dividing the period into periods and summarizing the events.

Although underwater construction using ships was carried out before the Meiji era, it was only after the Meiji era that heavy loads were handled using powered cranes, starting from the year crane ships were imported from the UK.

There are various theories about when the period ended, but the end of the high economic growth period was around the time of the oil shock, and the end of stable economic growth was around the time of the collapse of the bubble economy. In addition, the recent low growth period was divided into three periods. Period I was a period of low growth but continued high levels of public investment until around the time of the reorganization of central government ministries and agencies, Period II was a period of low growth and reduced public investment, and Period III was a period of public investment that was revived after the Great East Japan Earthquake, focusing on disaster recovery and national resilience.

a) 1891-1945: From the Meiji Period to the End of the War

The repairs to Yokohama Port were carried out under the guidance of the Englishman Palmer, and British port building techniques, construction methods, work machinery and work ships were imported.

b) 1946-1959: The period of recovery and recovery from the post-war chaos

World War II reduced Japan to ashes and dealt a devastating blow to the economy and society. The first five years were a time of recovery from defeat, but the economy expanded due to special demand caused by the outbreak of the Korean War in 1950. By 1955, the country had recovered to prewar levels, and the Economic White Paper stated that "we are no longer in the postwar period."

c) 1960-1972: High economic growth period (until the oil crisis)

Since 1960, the four major coastal industrial zones that drive the Japanese economy have recovered, heavy chemical industrialization has progressed, and "processing trade," which imports raw materials and exports finished products, has expanded. Among industries, the core industries of steel, oil refining, and related industries have grown.

d) 1973-1990: Stable growth period (until the collapse of the bubble economy)

Distortions began to appear in Japan's economy and society, which had continued to enjoy rapid growth. In addition to the pollution problems mentioned in the previous chapter, the first oil crisis hit the country. When the Yom Kippur War broke out, oil-producing countries imposed export restrictions and significantly raised crude oil prices, causing a sudden increase in oil prices, disrupting the world economy and causing consumer prices in Japan to soar.

e) 1991-2000: Low growth period I (economic stagnation, increase in crane ships)

Globally, economic globalization progressed with the fall of the Berlin Wall in 1989, the collapse of the communist bloc centered on the former Soviet Union in 1991, and the launch of the WTO in 1994. Meanwhile, in Japan, stocks and real estate, which had soared at the end of the 1980s, plummeted as the bubble burst.

The Great Hanshin-Awaji Earthquake occurred in January 1995, and the Port of Kobe suffered devastating damage. Thanks to the efforts of those involved, port facilities were restored in just two years, but the lost container cargo was never returned, and Japan's position in international container logistics declined.

f) 2001-2010: Low growth period II (deflation and reduced public investment)

At this time, public investment had already entered a declining phase, and public investment continued to be reduced against the backdrop of worsening national and local financial conditions. It was during this period that the "Public Works Cost Structure Improvement Program" was formulated with the aim of reducing the costs of public works.

g) 2011-2024: Low growth period III (aiming to escape deflation)

The Great East Japan Earthquake occurred on March 11, 2011. A large tsunami slammed into the Pacific coastline from Aomori to Chiba prefectures. A few days later, nuclear fuel melted down at a nuclear power plant in Fukushima prefecture. Learning from this disaster, efforts were made to "strengthen the nation's resilience." On December 2, 2012, a concrete ceiling panel collapsed in the Sasago Tunnel on the Chuo Expressway. Preventive maintenance had been implemented for about 10 years, but accidents due to inadequate maintenance did occur, and the importance of infrastructure maintenance was reaffirmed.

2. TECHNOLOGICAL TRANSITION

(1) 1891-1945: Meiji Period to the end of the war

a) Land reclamation work by Yokohama Customs

The construction work carried out by the Yokohama Customs in 1892 involved the mass production of uniformly sized concrete blocks, moving them around the yard using a stationary cranes, loading them onto transport ships, and then hoisting them into place using a crane ship.

b) Port construction by the Ministry of the Interior

The Ministry of Home Affairs' construction work, which began in 1922, included a variety of construction methods, including caissons for breakwaters, piers made of concrete blocks with a special structure called "cylindrical construction" on pine pile foundations, and L-shaped buttresses for quays. Crane ships were used to install square blocks for the breakwater's base and pine piles for the pier foundations, as well as to install precast panels for the pier superstructure.

c) Port construction outside Yokohama Port

From the Taisho era until the end of the war, the Ministry of Home Affairs' Port and Harbor Office was involved in breakwaters, quays, revetments, waterways, and land reclamation, and there is a record of one crane barge being stationed at the office, although the lifting capacity was not the same. The work carried out by the crane barge was mainly the "installation of square blocks" and "installation of L-shaped blocks," the same as at Yokohama Port.

d) Import of crane ships

During the Meiji period, Japan hired foreign engineers to provide guidance on port construction. The Port of Yokohama was built under the guidance of an Englishman named Palmer, and British port construction techniques and methods, work machinery and work ships were imported from Britain. Among these, the first crane barge was imported in 1891. By 1899, Japan was able to build a 15-ton lifting crane barge domestically, and in 1912, a 20-ton lifting crane barge with a fixed jib was developed and began to be used for salvage and ship outfitting.

(2) 1946-1959: The period of recovery and reconstruction from the postwar period of chaos

a) Construction and utilization of crane ships by the government

The government adopted the latest power and control technologies, and work boats for port construction were converted to diesel-powered or diesel-electric types, which enabled delicate work and improved lifting capacity, making it possible to handle larger materials. In addition, a winch system was developed for installing caissons, and crane ships began to be used for this work.

b) Use of crane ships in port construction by private businesses

The large crane ships acquired for the salvage needs were convenient for port construction, and they began to enter port construction. Kobe City made construction plans based on the capacity of the work ships, and the crane ships became increasingly larger. As the crane ships became larger, the scale of construction work for the reclamation and revetment of Kobe Port changed from the conventional concrete blocks (weighing about 30 tons) to caissons (weighing about 200 tons). Furthermore, crane ships came to be used not only for installing blocks, but also for large-scale pile driving work.

c) Construction of work boats

Immediately after the war, no new crane ships were built, and old work boats were repaired and used. However, there was a strong demand for port development for postwar reconstruction, and in 1948 the government included work boat maintenance costs in the budget and began to systematically repair and build work boats. At the time, the focus of construction was on dredgers, which were the most needed, but construction of crane ships also progressed. In terms of content, they were made larger than before the war, and their lifting capacity was improved. Private construction of crane ships began in 1950, when the Korean War broke out and the purchase price of iron rose, which led to demand from the salvage industry.

d) Power engines

As for power engines, diesel-electric and diesel-direct-drive engines came to be widely used instead of steam engines, and for power transmission and control, the Ward Leonard system was adopted for diesel-electric engines, while the torque converter system was adopted for diesel-direct-drive engines.

(3) 1960-1972: High economic growth period (until the oil crisis)

a) Construction of crane ships

Until the high economic growth period, many port construction works were directly managed by the government, and crane ships were built to develop technology, but after 1967, the government withdrew from general work ship construction. Meanwhile, crane ships rapidly grew in size as private companies began to own them.

b) Enlargement of crane ships and adoption of the caisson hoisting method

In 1961, a private company built a 480-ton crane ship, changing the caisson installation method at Kobe Port to the hoisting method. After that, the enlargement of caissons encouraged the enlargement of crane ships, and a positive spiral state continued in which companies tried to enlarge their caissons by observing this trend. In the Kansai region, an installation model was adopted in which caissons were manufactured in yards on land and hoisted by large crane ships. After that, caissons became larger, and crane ships also became larger accordingly. On the Pacific coast of eastern Japan, a caisson yard was set up in the port, and a method of launching and towing them on a slipway was adopted, and the two installation models came to coexist. In addition, the construction of marine bridges, which began in earnest during this period, also promoted the enlargement of crane ships.

c) Development of the winch method on the Pacific coast and customization of crane ships

The government developed the winch method of installing caissons using crane ships. In Onahama Port, a set of crane ships, push ships, and anchor lifting ships was built in 1966, greatly improving the efficiency of caisson installation work. In particular, crane ships were customized for breakwater construction and used to install caissons, foundation blocks, and wave-dissipating blocks.

d) Multipurpose crane ships

In the 1960s, wave-dissipating blocks became widespread, and their installation became the main task of crane ships, with installation methods being improved and evolved. In 1962, the government also built a self-propelled slewing crane ship, which was used for a variety of tasks, including the installation of blocks, caissons, sheet piles, and tetrapods. On the other hand, as large-diameter, long steel pipe piles came into use, pile driving work was shifted to dedicated ships.

e) Construction of general work vessels

In light of the increasing ownership of work vessels by private companies, the government has shifted its focus away from the construction of general work vessels and towards technological development. Private companies are now the ones who own the work vessels and carry out construction work on site.

(4) 1973-1990: Period of stable growth (until the collapse of the bubble economy)

a) Double-suspension erection using two large crane ships for the Honshu-Shikoku Bridges

18 bridges were built on the Honshu-Shikoku Bridges, and the bridge girders were erected using the large block all-at-once method. The heavy bridge girder block was the 5,590t truss bridge (total length 185m) on the Seto Ohashi Bridge at Hitoishijima, which was hoisted by two crane ships, the largest in the world at the time, with a 3,500t lift and a 3,000t lift, and the joining work was carried out at a height of 80-90m above sea level. The crane ships were also used not only for the all-at-once erection of the bridge girders, but also for the installation of the steel shell caissons for the substructure and the erection of the pilot ropes for the suspension bridge.

b) The role of crane ships in the construction of the revetment and bridge at Kansai International Airport

The reclaimed revetment was constructed at a high pace, covering a length of approximately 10.5 km, in approximately 2.5 years. The caisson revetment was constructed by installing vertical wave-breaking caissons using a large crane ship, while the steel cell revetment was constructed by installing a vibro hammer on a crane ship. The wave-breaking blocks for the gently sloping masonry revetment were also installed using a crane ship.

c) Marine development and the use of crane ships

There has been an increase in the construction of facilities in areas with great depths and high waves. As the top height of the foundation rubble mound for the breakwater at the mouth of Kamaishi Bay is 30m deep, the government conducted a demonstration experiment to replace manual leveling with mechanical leveling. The role of the crane ship is to act as a "support ship" loaded with equipment for changing the position of the leveling device and control it. Crane ships have also come to be used for the task of "mechanical leveling."

d) Use of crane ships for the installation of gantry cranes, etc.

As container cargo increased, the need to install gantry cranes on quays increased. Since crane ships became larger and it became possible to install gantry cranes, this work has become commonplace.

e) High performance using information technology

A movement has begun to introduce construction management systems that utilize computer and measurement technology to improve construction accuracy and reduce labor.

f) Number of crane ships owned

The transition from the period of high economic growth to the period of stable growth led to a reduction in public investment. Investment in work boats was curtailed due to a decline in domestic construction. During the period of stable growth, the number of crane ships owned remained almost unchanged. In 1987, a crane ship with a lifting capacity of 4,100 tons, the largest capacity to date, was built, but no crane ships with a larger capacity have been built since. Many of the "suspended loads" such as bridge girders exceed 4,100 tons, but the method chosen to overcome this was to use a technique known as "multiple lifting" using two or three ships.

(5) 1991-2000: Low growth period I (economic stagnation, increase in crane ships)

a) Development of the Tokyo Bay Aqua-Line and use of crane ships

The Tokyo Bay Aqua-Line was constructed using a crane barge. Kawasaki Artificial Island is the starting shaft for the only shield tunnel built in the sea. The crane barge is responsible for the main tasks, including installation of the jacket that forms the outer shell, excavation of soil, installation of the main structure, transportation of materials and equipment, and introduction of the shield machine.

Kisarazu Artificial Island is the connecting section that transitions from the tunnel to the bridge. The aim was to shorten the construction period by using a steel shell caissons and a steel sheet pile cellular structure and installing them using a crane barge. The bridge section is made of steel piers, which are installed all at once using a crane barge before concrete is poured, and the bridge girders are erected by extending the span and hoisting them together using two crane bars.

b) Technology for improving the efficiency of offshore hoisting operations

GPS-based positioning technology was developed, and by the 2000s it had become widespread enough that most ships were using it. It was also used to manage the dumping of landfill soil for the second phase of Kansai International Airport. On-site technology development for the removal and installation of wave-breaking blocks was promoted by the government and private companies. In addition, equipment to improve maneuverability, such as construction management systems using sonar and walking spuds and side thrusters, began to spread.

(6) 2001-2010: Low Growth Period II (Deflation and Decreasing Public Investment)

a) Construction of Tokyo Gate Bridge

A system was developed to monitor the movements of all three ships on each crane ship, and GPS antennas and other measuring devices were installed on the crane jib top and other locations to manage load, height, position, and check the position of the girders. Offshore hoisting work requires "placing the ship gently" and depends heavily on the skill of the operator, but obtaining on-site information in real time supports the work.

b) Bridge erection

The "Megami Ohashi" bridge in Nagasaki Port is a cable-stayed bridge, and four parts, the "main tower," "inclined bent," "main girder," and "climbing crane," were installed in a series of construction works. In particular, it was reported that the erection of the inclined bent was carried out using a combination of two crane ships.

c) Number of vessels

Public works expenditures continued to decline against the backdrop of the worsening national financial situation. The number of vessels, both self-propelled and non-self-propelled, peaked in 2001 and then began to decline. The rate of decline grew larger each year, and between 2007 and 2009, the number of vessels fell by more than 100 vessels. However, between 2009 and 2011, despite the impact of the Lehman Shock and the continued decline in public works, the decline leveled off to a decrease of 37 vessels.

d) Equipment

In this period, equipment such as thrusters, spud maneuvering systems, and construction management systems using GPS became quite widespread. Many crane ships were retrofitted to already constructed ships during this period. The IMO first phase of gas emission regulations began in 2005, and crane ships equipped with engines that met the regulations appeared from construction in 2006.

(7) 2011-2024: Low growth period III (Aiming to escape deflation)

a) Response to the Great East Japan Earthquake and tsunami countermeasures

For the work of clearing the sea route, work vessels equipped with cranes, such as crane ships, gutter ships, and grab dredgers, were requisitioned. In addition, during the restoration process, crane ships were used to return ships that had washed up on land back to the sea.

b) Offshore wind power generation

Offshore wind power generation is carried out in offshore waters with high waves, and SEP vessels are used. In recent years, SEP vessels have been built by major companies, but the size of the wind turbines has become larger along the way.

c) Number of crane ships

The number of crane ships, both self-propelled and non-self-propelled, began to stop decreasing in 2011, when the decline in public works projects had not yet subsided. Since then, although the number has decreased, the decrease rate (compared to the previous period) has remained within 10%. As for equipment, side thrusters, spuds, GPS, and sonar are becoming more common. As for other equipment, there are many examples of soundproofing devices being installed. There are also examples of improving the comfort of crew members, such as increasing the size of rooms and introducing Wi-Fi on board. As for environmental performance, there has been an increase since 2011, mainly in the area of CO_2 reduction. Many common initiatives, such as installing solar panels and switching to LED lights, are being implemented, but advanced hybrid systems and storage battery systems are also being introduced.

3. CONCLUSIONS

Japan's crane ship technology has developed significantly in a short period of time. In 1912, a crane ship was able to lift 15 tons, but 75 years later, in 1987, it had developed into a ship capable of lifting 4,100 tons of weight. With the decline in port construction, the number of crane ships is on the decline, and the construction technology of crane ships is being passed down. We are confident that this document will be useful in the construction of crane ships in the future.

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