FIELDS WITHIN CIVIL ENGINEERING – PORTS AND CANALS AS WATERBORNE TRANSPORT FACILITIES

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Contents

Summary

An overview of historical development of ports and canals in the world as the fundamental facilities for waterborne transport is given to supplement the four chapters (*Transportation Engineering*, *Urban and Community Planning*, *Wastewater Management Engineering*, and *Water Resources Engineering*) in the topic of “Fields within Civil Engineering.”

Development of ports and canals are sketched in four ages of the ancient world, the seventh to fifteenth centuries, the sixteenth to nineteenth centuries, and the twentieth century. Emphasis is made on the social and economic benefits of port and canal constructions in respective ages. Projects typical of each age are described as examples.

They include: Ostia Port for Rome, Grand Canal of China, Midi Canal of France, canal network of England in the late eighteenth century, Erie Canal of America, London Port and transoceanic trade ports in the nineteenth and twentieth centuries, Suez and Panama Canals, and hub and feeder ports for containerships.

Some technical aspects of port and canal constructions are presented to remind the readers of the scale of civil engineering works though not in detail.

1. Introduction

The present chapter at the topic level, "Fields within Civil Engineering," comprises of the four article level chapters on *Transportation Engineering*, *Urban and Community Planning*, *Wastewater Management Engineering*, and *Water Resources Engineering*). The areas covered by these chapters are quite diverse, but they deal with technology development for betterment of civil society. To supplement these chapters, a historical development of civil engineering facilities related with the waterborne transport is discussed here.

Since the ancient times, a civilization meant a growth of cities where many people lived together. A large amount of food, fuel, and other goods had to be supplied to cities to support people. The imperial capital of Rome in the first century annually imported 17 million bushels of grain from Africa and Middle East to feed the population of more than one million. They were mostly transported by ships across the Mediterranean. The Emperor Yang of the Sui Dynasty of China in the seventh century built two rice depots with 1 million ton capacity each at Luo-yang to store rice carried through the Grand Canal.

Waterborne transport is far more efficient than land transport; a barge in old days could transport cargo of about 10 ton per crew, while a man controlling a few horses could handle several hundred kilograms of horseback cargo only. The speed of waterborne transport may be lower than land transport, but a long distance transport of grains, rice, and other bulky cargo could only be possible by means of ships. Throughout the ages, people endeavored to provide and improve the facilities for waterborne transport.

This chapter provides a historical overview of the development of ports and canals as the waterborne transport facilities from the ancient through the medieval, the modern, and the contemporary ages. Major projects at respective ages are discussed to demonstrate the importance of waterborne transport facilities for civilizations. A prospect of the future development is given in Section 6.

2. Ports and Canals in the Ancient World

2.1. Irrigation Canals and Rivers for Waterborne Transport

Civilizations had begun with cultivation of cereal such as corn and rice. The yield of cereal increased greatly by irrigation. Mesopotamian people developed a large-scale network of irrigation canals to bring water from the Tigris and the Euphrates to cornfields since the fourth millennium before Christ. The canals also served as the main route of transporting crops and other goods. However, the canal system required constant maintenance by dredging the channel bottom and protecting embankments, because of heavy siltation and frequent floods. Canal maintenance was one of the most important duties of the kings. For example, the oldest law by Hammurabi of the first Babylonian Kingdom in the early 18th century before Christ had four specific articles for regulations aimed at good maintenance of canals among 282 articles in total.

In ancient Egypt, cultivation was facilitated by storing floodwater of the Nile for several weeks in temporary basins to provide soil with enough moisture and nutrients. The Nile itself was the artery of transportation. Millions of blocks of limestone that were laid upon to form the Great Pyramids were all transported from the quarry to Giza by barges. Simple quays might have been built along the riverbanks to load and unload the stone blocks.

China had also constructed many canals for irrigation and transportation since the old days. One of the oldest records is the flood control weir of Du-jiang at Chen-du in Shi-chuan Province built by the governor Li Bing in around 250 BC. Many channels were cut across the plain to supply water from the weir, and the rice yield was multiplied many times to feed the population of Chen-du area. The weir Du-jiang has been keeping its function until the present through maintenance and updating works from time to time. Shi Huang-di, the first emperor of the unified China, ordered to build the 34 km long canal Lian to open the route to Gui-ling from the great river Chang-jiang in 214 BC. The canal crossed over the hilly area with 32 water gates to increase the water depth for passage of barges. The canal well served for the army of Shi Huang-di to conquer the Southern China and the Northern Vietnam areas.

2.2. Port Construction in the Ancient World

Sea transport had been the means of prosperity in the Mediterranean since the Minoan civilization at Crete in around 2000 to 1700 BC. Phoenicians commanded the Mediterranean trade in the early first millennium before Christ. Tyros was the central city of port, which was sheltered by two offshore islands artificially joined together. Phoenicians built many colonial cities around the periphery of the Mediterranean. Carthage built by Phoenicians prospered even after Tyros was destroyed by Alexander the Great in 333 BC, but it was finally perished by Romans in 146 BC. Carthage built two ports, one for commerce and the other for navy, dug out of coastal land. Greeks followed Phoenician in establishment of colonial cities around the Mediterranean. Colonial cities were built around small bays that provided harbors to maintain sea communication with their mother cities. Harbors were protected by moles built with layered stone blocks. The entrance of a harbor between the heads of moles was closed by iron chains against enemy ships. The port of Piraeus for the city Athinai (Athens) was such an example.

When Alexander the Great built the city of Alexandria in 331 BC, the water area behind Pharos island was used as the harbor, which grew to the big port of the Ptolemaic Kingdom. Pharos island was connected to the land by a 1300 m long mole, two harbors were provided at the both sides of the mole with additional breakwaters, and the great lighthouse of 110 m high was built at the east of Pharos island. Later, Alexandria Port functioned as the main port of grain export to Rome. The City of Alexandria prospered during the time of the Roman Empire with the population of nearly one million.

The main port of grain import was Ostia near the mouth of Tevere (Tiber) River, which was built by the Emperor Claudius I (41 to 54 AD) with extension of two arc-shaped breakwaters of about 900 m and 800 m long from the beach. The Emperor Trajanus (Trajan) (98 to 117 AD) dug out a hexagon harbor of 35 hectare in area with the side length of 340 m each to provide a sufficient length of quay for grain unloading operation. Trajanus also built an artificial port of Civitavecchia to supplement Ostia Port, by projecting a 420 m long mole from the coast to a depth of 7.2 m and building a 350 m long offshore breakwater at a depth of 6.6 m. They were composite type breakwaters with masonry walls placed on rubble mound foundations. Roman engineers built many port facilities; some breakwaters were built with arched piers in the sea as depicted in the fresco painting at that time. They used concrete by mixing special volcanic ash for underwater construction, as described in De Architectura Libridecem (Ten treatises in architecture) by Vitruvius.

All the technology was lost after the Roman Empire had collapsed through big waves of the German tribal wandering. Urbanized societies and civilizations disappeared, no long-distance trade was necessary, and waterborne transport was kept minimal in Europe during the early medieval age.

3. Ports and Canals in the Seventh to Fifteenth Centuries

3.1. Grand Canal of China

In contrast to the medieval Europe, China continued to prosper since the Qin Empire that unified China in 221 BC, even though many dynasties rose and fell one after the other. The prosperity of China was supported by waterborne transportation in the big rivers of the Huang-he (Yellow River), the Chang-jiang (Yangtze River), the Huai-he, and others, which mostly flow from the west to the east. The transportation from the south to the north was undertaken by various canals that connected rivers. The largest among them was the Grand Canal of 1800 km long, completed by the Emperor Yang of the Sui Dynasty in 608.

An early south-north canal was that connecting the Chang-jiang and the Huai-he built in 486 BC and another to connect the Huang-he and the Huai-he in the fourth century before Christ. The Emperor Yang expanded the then-existing canals in a large scale by mobilizing more than one million laborers including many women in three stages. First, he improved the canal from Yang-zhou at the Chang-jiang to the Huang-he near Luo-yang in 605. The canal was 60 m wide to accommodate large ships. Then, he dug the northern canal to reach Tong-xian near Beijin in 608. He finally extended the canal to Hang-zhou in 610.

The Grand Canal had served Chinese Civilization as the most important artery of transportation up to the early twentieth century. Without the Grand Canal, residents of metropolises of China could not sustain their daily lives. However, maintenance of the Grand Canal was a grave burden for every dynasty. The main reason was the siltation by an enormous amount of wash load of the Huang-he. Dredging had to be made year after year under supervision of the special office dedicated for it. The Huang-he also changed its route wildly after several major flooding, and the Grand Canal was rerouted many times.

In the early times, ship-towing slopes were built to overcome the level difference and ships were pulled up and lowered down by laborers. In the eleventh century during the Song Dynasty, single-gate locks were built at 79 locations to relieve the labor of ship towing. When a ship is rowed or pulled upstream, the gate is closed behind the ship and the water level gradually rises as the river pours into the temporary pond. Then the ship moves again upward along the canal. A ship moving downstream is flushed down the canal with the water released by opening of the gate. In 1293 during the Yuan Dynasty, the canal route was changed to cross over a small summit of about 15 m high, and seven locks with a double system of gates were built. A lock chamber is equipped with two gates upstream and downstream. When a ship moving upstream or downstream enters into the lock chamber, the both gates are closed until the water level in the chamber becomes equal to the water level of the channel of canal into which the ship moves in. By this system, the volume of water released with each passage of ship is greatly reduced in comparison with that of the single-gate lock system. Use of lock systems in China was much earlier than in Europe.

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Biographical Sketch

Yoshimi Goda is Professor Emeritus at Yokohama National University in Japan since 2000. He received Dr.Eng. and B.E. from the University of Tokyo, and M.Sc. from the Massachusetts Institute of Technology. He served as the Director General of the Port and Harbour Research Institute, Ministry of Transport, Japan and then as Professor of Yokohama National University at the Department of Civil Engineering. He has been working on the research field of ocean waves and structural interactions and have published "Random Seas and Design of Maritime Structures (2nd Edition)" from World Scientific, Singapore, and other technical books on port and coastal engineering in Japanese. He also published two Japanese books on the history of civil engineering from the viewpoint of interrelation with world civilizations.