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目　次 (CONTENTS)

1．Planning and Technology for lock Canal upon History
— From Medieval Canal to the Panama Canal —
……Masataka NAGANO…… 3
(運河計画論史　—中世の運河からパナマ運河までの閘門式運河—
……長野正孝)

2．我国沿岸の潮位と平均海面の変動の解析
……村上和男・山田邦明……37
(Analysis of tide gauge records and sea-level change around Japanese coast
……Kazuo MURAKAMI and Kuniaki YAMADA)

3．円筒構造物のコンクリート打設直後の温度応力解析
……清宮　理・山田昌郎・長廻幹彦……71
(Thermal Stress Analysis for Cylindrical Concrete Structures
……Osamu KIYOMIYA and Masao YAMADA and Mikihiko NAGASAKO)

4．水平管における空気混入軟泥の流動特性（第二報）
……岡山義邦・鮎貝基和・鈴木　誠・福本裕哉……97
(Fluidity Characteristics of Muddy Slurry with Compressed Air in Horizontal Pipe (2nd report)
……Yoshikuni OKAYAMA, Motokazu AYUGAI, Makoto SUZUKI and Hiroya FUKUMOTO)

5．杭打施工管理システムの開発
……石塚浩次・根本孝志・林田善久……127
(Developent of Execution Control System for Pipe Driving
……Koji ISIZUKA, Takashi NEMOTO and Yoshihisa HAYASIDA)

港湾技術研究所報告
第31巻第3号　(1992．9)

1．運河計画論史
—中世の運河からパナマ運河までの閘門式運河—

長野正孝

要　旨

パナマ運河は，20世紀初頭に世界最大の模造物として完成したが，中世の運河からそれに至るまで永い技術進歩の歴史があった。すなわち，16世紀初頭に中米地峡運河の必要性が叫ばれ，幾多の技術者の手によって，多くの計画が試行錯誤を繰り返しながら提示され，やっと今世紀初頭に生まれた計画が現パナマ運河として実現したのである。

本編では，世界の運河技術の発展過程，主としてパナマ運河を中心に閘門式運河の計画と技術の変遷を分析，評価し，以下のような結論を得た。

第一に，世界の閘門式運河は，中世の時代から19世紀初頭までは，ゆるやかな進歩を遂げており，その時代の未成熟な技術では，中米地峡には，どのような小さな運河も建設することは不可能であった。日本でも改修河川の舟運は中世から発達し，一部には堰によって水位を調節するような運河の誕生も見られたものの，ヨーロッパのような技術レベルには達しなかった。近代運河も，明治以降に導入されたが，国土，河川環境や気候条件の違い，鉄道の普及などから，発展を持続するところとはならなかった。

第二に，伝統的な閘門をつないで大きな落差を克服するシステム技術が，1820年代に生まれ，1870年代まで欧米の運河網の拡大に寄与した。19世紀半ばには，中米地峡運河にもこの概念を利用して幾つかの提案が行なわれた。しかしながら，当時，大型化が始まっていた蒸気船の要請を満足させるために船舶運河という新しい概念が登場し，さらにより新しい技術とアイデアを必要とした。

第三に，レセップスがパナマ運河に挑戦した1880年代には，鋼鉄製ゲート，コンクリート閘門，ダイナマイト，浚渫船，堀削機械などの土木技術は揃い，小さな運河であれば，中米地峡運河は技術的には可能になっていたことが判明した。

第四に，上記の幾つかの重要な技術の中で，鋼鉄製閘門ゲートと重力式コンクリート構造が，高水位差を克服するために不可欠であったことを明らかにした。また，フランスとアメリカの技術者によって設計された現パナマ運河のプロトタイプと19世紀の世界の主な港湾のコンクリート構造物の関係について述べ，当時の課題であった海水劣化対策，閘門設計技術の変遷について分析した。また，中世からパナマ運河までの閘門の構造の変遷についても明らかにした。

第五に，パナマ運河の最近の一連の計画と堀削土量の変遷について評価し，将来の運河のあり方を展望した。

キーワード：閘門式運河，技術史，パナマ運河，計画，構造

REPORT OF PORT AND
HARBOUR RESEARCH INSTITUTE
Vol.31, No.3 (Sept. 1992)

1. Planning and Technology for Lock Canal upon History — From Medieval Canal to the Panama Canal —

Masataka NAGANO

Synopsis

The Panama Canal emerged as one of the largest structures in the world in the beginning of the 20th Century. There had been a long history in the development of canal technology from medieval times to its realization. In other words, from the time the need for a canal became clear in the beginning of the 16th Century, many engineers have made plans struggling with trial and error, until finally canal became a reality in the beginning of this Century. The following conclusions were found after studying the technologies and planning throughout the history of world canal development.

First, this paper clarified that the features of the lock canal have made sluggish progress from medieval times until the beginning of the 19th Century, and also proved that predessesors had not been able to construct any primitive canal in the Isthmus due to immaturity of technologies before the 19th Century. As for Japan, navigable artificial waterways had also been developed from medieval times as well as in Europe. A few trials for flashing system by wier or sluice had been recorded, however, those technologies remained at a lower level than that of Europe. Modern canal was also introduced after the Meiji Restoration, but had not been developed due to difference of conditions.

Second, a device which is able to overcome large waterhead by stretching many traditional masory locks like a staircase was invented in 1820's, and it spread throughout Europe. As for transisthmian canal, unique plans were drafted by applying the idea in the middle of the 19th Century. However, a new concept called ship canal that called for the transit of large steam ships was emerging and the concept required new technologies.

Third, we concluded that they would have been able to construct a small canal in Panama in the era of de Lesseps 1880's, most necessary technologies such as concrete lock with steel gates, dynamite and excavating and dredging machines had already emerged.

Fourth, this paper clarified the reason why iron and steel gates and gravity concrete structures for isthmian canal were needed from viewpoint of structural engineering among aforementioned technologies. These were able to withstand large water pressure. Explaining the design of prototype of the Panama Canal executed by French and the U. S. engineers and outstanding port facilities in Europe in the 19th Century, chronological development for design of massconcrete structure and countermeasures against erosion of concrete caused by salt water was analyzed. And trend of lock features was from medieval times to the Panama Canal was also stated.

Finally, this paper showed the chronological trend of incremental excavated volum erelated to the many recent Panama canal plans, and drafted an appropriate canal plan for the future.

Key Words : Lock Canal, Engineering History, the Panama canal, Planning, Structure

Contents

Synopsis ······ 3

1. Introduction ······ 7

2. History of the Lock Canal ······ 7
2. 1 Prehistory ······ 7
2. 2 Canal Age in the Industrial Revolution ······ 10
2. 3 Limitation of Locks and Others ······ 12

3. Difficulty of Isthmian Canal Project ······ 14
3. 1 Identification of Preferable Canal Route ······ 14
3. 2 Labour Power ······ 15
3. 3 Tropical River and Mountaionous Routes ······ 16

4. Key Ideas and Technologies for Realization of Isthmian Canal ······ 16
4. 1 Multi-Stairs Lock Canal ······ 16
4. 2 Steel Gate ······ 19
4. 3 Topographic Survey ······ 19
4. 4 Artificial Lake Concept ······ 20
4. 5 Geo-technologies ······ 21
4. 6 Mass-Concrete Structure ······ 22
4. 7 New Filling and Discharging System for Large Lock Chamber ······ 24
4. 8 Excavating Engineering and System ······ 24
4. 9 Planning of Waterway ······ 26

5. Issues for the New Panama Canal in the 20th Century ······ 27
5. 1 Relation between Vessels and Waterways ······ 27
5. 2 Problem of Augmented Canal Project ······ 28

6. Conclusions ······ 31

References ······ 33

1. Introduction

Mankind first saw the need for a transithmian canal over 400 years ago. Over the years, many plans were proposed but none were realized until 1914, when the present Panama Canal was constructed. Since the completion of the present Panama Canal, one of the world's biggest structures in 1914, new canal plans have also been proposed on several occasions but have never realized due to constraint of lock canal.

Firstly, this paper analysed chronological development of world lock canal and lock structures, scale and material from medieval times from the viewpoint of engineering. This is because the process of development of planning for the transisthmian canal has been closely related with the development of the world canal.

It has been said that Japan was not a part of the Canal Age which started before the end of the 18th Century. This paper clarified the roots of the traditional Japanese canal concept and technology providing a comparison between the Western and Japanese canal.

Secondly, with remarkable augmentation of vessel from the 19th Century, chronological augmentation of cross section of waterway for the plans and technological level of each era including the present Canal were analysed and presented.

Finally, a comparison between the augmentation of excavating volumes of the series of the plans and those of recent large Japanese projects was executed, and issues confronting the second Panama Canal are depicted.

As for Japan, few studies have been executed except technological surveys 「Interoceanic Canal Study 1970」 by the U.S. and future demand analysis concerning the present Canal. It is the novelty of this paper that it analized chronological development of technologies on lock canal from beginning to present. As for the Panama Canal, a second Canal had been requested before World War II. Prior to undertaking the project, we, Japanese engineers, will have to study its whole history, because predecessors have been offering insights to overcome obstacles which we will have to confront again in the near future.

Today in Japan, having stressed road transportation since the 1970's, we are confronted with serious environmental and social problems such as air pollution by NO_X and CO_2, daily traffic jams especially in urban area. Now is the time to assess the whole urban transportation system and to reevaluate canal transportation system to mitigate the adverse impact on the urban environment.

2. History of the Modern Canal

2.1 Prehistory

(1) European Lock Canal

Canals have been in existence since ancient Egypt, used primarily for irrigation and inland navigation. A devices called "flash" , which involved wier or dam to control the stream of navigable waterway, appeared before the 11th Century. With the increase in traffic, a better, more reliable system called lock system was invented in medieval times. By the end of the 14th Century, a few modern lock canals could be seen: the Brugge, Stechnitsz and Milano canals are deemed as the first modernized lock canals in Europe[1),2),3)]. **Table.1** shows a representative lock canals up to the 17th Century.

The earliest lock canals consisited merely of a length of canal or river divided off by two pairs of gates. The intervening chamber were formed often unprotected natural banks, but continual scour from the sluices soon made it desirable to be protected by timber sheeting or masonry.

Years passed and traditional lock system in Europe was formed with brickwork or masonry chamber and wooden leaf gates for adjusting and withstanding waterhead in sluggish stream. They were large enough to hold at least one small craft using waterway, and the water depth could be controled[3)].

In the latter half of the 15th Century, miter gate, widely used lock canal at present, was born in Italy. In the

1450's Leon Battista Alberti, a famous engineer and architect, proposed the idea for the first time, and in 1497, Leonardo da Vinci applied this concept to the Milano Canal[1),4)]. Many wooden miter gates spread to European lock canals in the 16th Century. But, due to lack of strength of material and structure, waterhead between up and down stream of a pair of lock gate leaves have had to be limited empirically to less than 5m until the end of the 19th Century[4)].

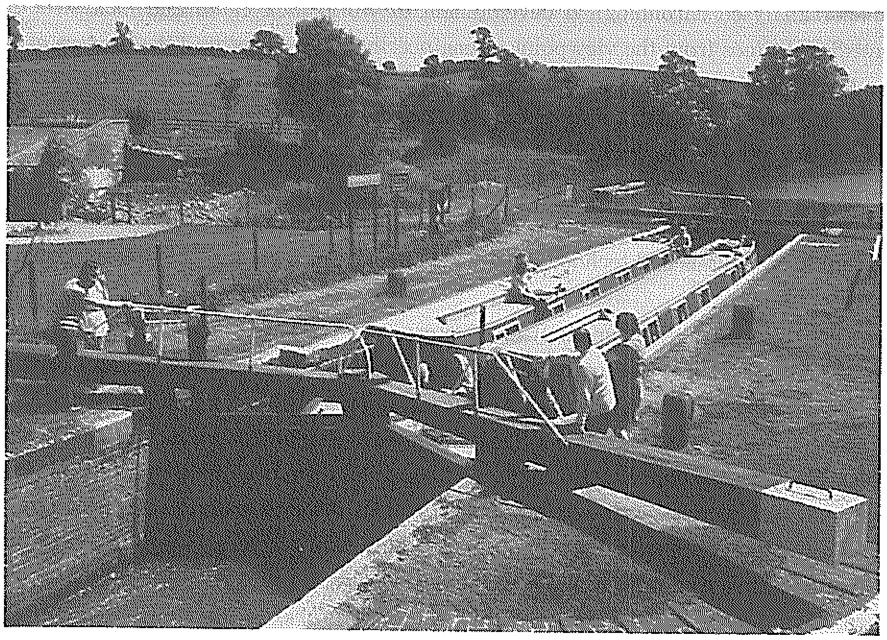


Photo.1 A Typical Traditional Lock in Europe
(By Courtesy of the British Tourist Authority)

(2) Asian Canal with Sluice

In China, the first canal network entering Tensing was developed to unify the nation in the 3rd Century. In the Chui Dynasty of 611, Emperor Yantei built the Great Canal, a 2,400km canal that formed a waterways network in the central plain for conveying army troops, irrigation for paddy fields and other products. Those Chinese canals had a unique stream control system, which were comprised of a series of single leaf wooden gates without lock chamber through a unit of canal. Throughout Chinese history, a lock canal with miter gates and chambers like those in Europe were never developed.

In Japan, although topographic and climatic conditions formed rapid and small streams unlike those of Europe and China, improvement in navigation had been made.

Since most rivers are steep, seasonal floods were unavoidable disasters until the 20th Century. The first man-made inland navigable waterways had networked in Settu, around the Yamatogawa river that originated in Nara, the capital of Japan to Osaka Bay in 678. The technology of water work was transferred from China at that time. As years passed, river improvement and navigable waterways were spread all over Japan by the 17th Century. In the Edo era, the Tokugawa Dynasty, famous canals were the Onga-Horikawa (1600-1804) Canal in Kita Kyushu, the Takasegawa (1611~1618) Canal in Kyoto by a famous merchant, R. Suminokura, the Teizan Bori Canal (1597-1673) in Miyagi, the Yodo and Ajigawa rivers in Osaka[6),7),8),9),10)]

Many primitive masory sluices with wooden plates were also recorded in the era: most of them employed a flash system called "kaku-otoshi" by using wooden planks which could be adjusted one by one to control the level of water. Representatives were the Takasegawa Canal and Minuma Tuusen Bori[7)].

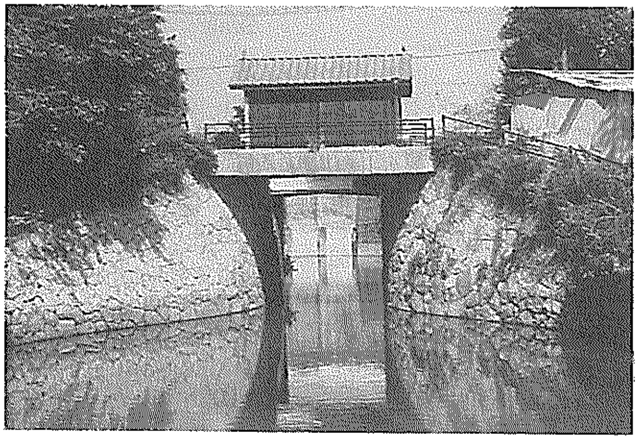
Table.1 Lock or Sluice Canals in Medieval Times (14~17th Century)

	Name of Canal	Location	Scale
1394~96	Brugge[1]	Belgium: Damme Locks	Lock: Length 30m, Width 10m
1391~98	Stechnitsz[1]	German: connected Baltic S. and North S.	Max. Barge Length 10m, Width 3.3m
1482	Milano[1,2]	Italy: By L. da Vinci	6 Locks: the First Miter Gate
1548	Paderno[1,2]	Famous Canal in Italy	Lock: Length 30m, Width 8m, Gate Width 3.3m
17 C.	Kurayasugawa	Japan (Okayama Pref.): Yoshii Lock	Outstanding Masonry Lock Canal in Japan in the 17C. :Gate Width 3m
1600 ~1802	Onga-Horikawa[6]	Japan (Fukuoka Pref.): Nakama & Jime locks	2 Masonry Locks: Width 3m, Wooden Gate 3.3m×3m
1605~42	Briare[1,5]	French: connected Seine R. and Loire R.: 6,000 soldiers were engaged in its construction.	Representative Canal in the 17th Century : 54km Length : conquered 120m of waterhead by 40 locks : Width of waterway 12m, depth 1.2m
1611~18	Takasegawa[7]	Japan, Kyoto City	Canal Width 6.4m, Primitive Wier
1682~92	Orlean[1,2]	French : connected Seine R. and Loing R.	74km Length : 69m waterhead : conquered by 27 wooden gates
1666~92	Langue doc[1]	In the era of Louis XIV, J.B. Colbert built the canal connecting Bay of Biscay and Mediterranean in 1869. 8,000 soldiers were engaged in its construction.	Representative Canal in the 18th Century: Width of waterway 19m (sur face), 10m (bottom): Depth 2m: Length of Lock 35m, Width 6.3m: Waterhead of each lock 2.4m: Resovior of summit 7million m^3 Biscay Bay side: 63m of waterhead, 51km length by 26 locks Mediterrean side: 186m of water-head, 184km length by 74 locks

Shown in **Photo.2**, an outstanding lock canal, the Yoshii Lock was constructed in the era and still exisits in Okayama Pref. for the purpose of adjusting a waterhead between two rivers: This lock has two gates and a large chamber. However, throughout its history, a massive lock canal like that in Europe was not developed in Japan.

(3) Trial for Isthmian Canal

The development of isthmian canal projects has been closely related with that of the Western canal mentioned before. The Central American Isthmus stretches 2,800km from Tehuantepec in Mexico to the Atrato River in Colombia. Columbus' planned voyage toward India had been blocked by the Ishumus in 1502, and though he believed it was India, ofcourse, it was not at all. Eleven years later, in 1513, Vasco Nunes de Balboa had crossed the Isthmus and found the Pacific. Colombus and Balboa made motives of mankind to seek canal route through the Isthmus. Hernando Cortez was said to be the first advocater of building an isthmian canal. He wrote to Charles V in 1524; "If a strait is found, I shall hold it to be the greatest service I have yet rendered. I would make the king of Spain master of so many lands that you might call yourself lord of whole world"[11]. In the Spanish era, any undertaking for transisthmian canal was difficult due to steep slopes of the moutainous topography and to tropical river in dense jungle.



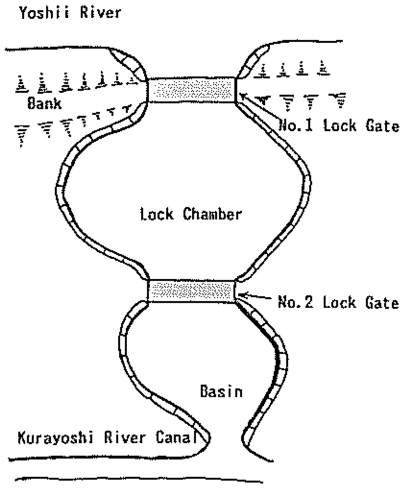


Photo.2 The Yoshii Lock in the Kurayasu River Canal, a representative Japanese Sluice (By courtesy of Prof. Y. Nagahiro)

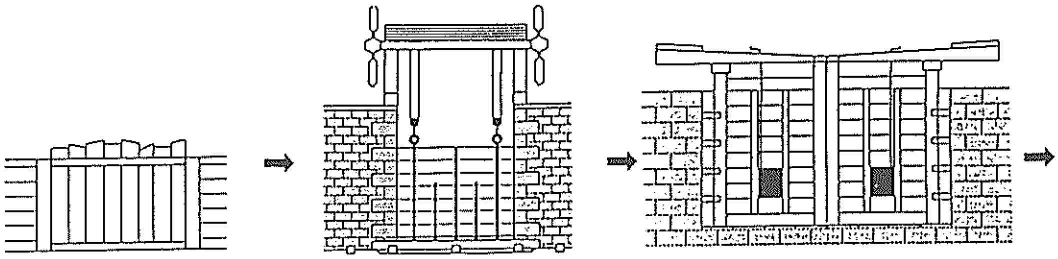


Fig.1 Development from Sluice to Lock in Europe

As for canal plan in Spanish era, although no details were recorded except stories of surveys and expeditions, scale of plans that they might have considered can be presumed upon tiny waterway with small masonry locks in Medieval times ; since an engineering system to build the Orlean and Langue doc canals in the end of the 17th Century existed, a typical low waterhead canal in sluggish waterway which were some 30m of length, 10m in width and 2~3m in depth at most, not for large ocean going sailing ship, but for small barge less than 100tons could be realized at that time.

But, the rivers in the Isthmus were very steep and conditions were different.

Furthermore, through the age of Spain, canal project had had vigorous opponents as well as enthusiastic supporters. The oppsition said: a canal would benefit other maritime nations more than Spain itself; on account of the supposed difference of surface level of two oceans, a waterway causes disastrous inundations; and the construction of an artificial water channel where God had seen fit to space a land barrier would be an impious and sinful act[12].

2.2 Canal Age in the Industrial Revolution

With the progress of the Industrial Revolution, barge canals were developed and spread in Europe. The first entirely artificial canal in the U.K. was the Bridgewater Canal. It was proposed for conveying coal from the Worsley mine to Manchester by Duke of Bridgewater, designed by James Brindley, and built in 1761[2),5)]. By 1830, a canal network with a total length of 3,100km canals was fashioned in England and Wales.

Furthermore many cross-country canals, waterways such as the Kennett and Avon, the Thames and Severn, the Forth and Clyde rivers and the Caledonian Canal were developed by the first half of the 19th Century[2),5),13)].

In France, where the spread of the Industrial Revolution was somewhat slower as a result of the French Revolution and Napoleonic Wars, the developed canal network amounted to only 900km by 1830. However, by 1848, it had reached 2,900km, and covered the northern area of the Seine river[2),5),14)].

In Germany, canals were developed to connect the Reine, Weser, Elbe, Order, Danube and other rivers by the middle of the 19th Century. The famous canals in Germany were the Midland connecting the Elbe and Reine rivers, and the Regnitz connecting the Reine and Danube rivers. 7,000km of navigable waterways are extended today[15)].

In Italy, having developed famous canals in medieval times, navigable waterways were limited in the northern area.

The most famous Swedish waterway was the Gota Canal which was built in 1831 as a cross-country canal between Gothenburg, facing the Skagerrak Strait, and Stockholm, the capital of Sweden. It served for carrying inland natural resources[2),16)].

In the U.S., many ideas and suggestions for canals connecting the Great Lakes and rivers of northeast part of the U.S. surfaced in the 18th Century, and some short distance canals were actually built before the 1820's: the Santee and Cooper Canal and the Middlesex Canal were ambitious canals for the late 18th Century, while the most famous Canal in the U.S., the Erie Canal, connecting Lake Erie and New York was completed in 1825. It had a great economic impact on the New York Port[2)].

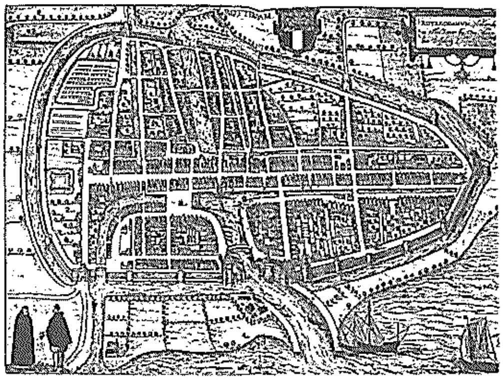
In Holland, considering her geographical condition, it was inevitable that many canals would be built there. Entering the age of the great voyage, many new ports were built in the estuary of the Rhine. However navigable channels through branches of the Rhine were constantly changing and maintenace of the channels was a difficult task.

Hence, until the beginning of the 19th Century, sea-going vessels could only reach Amsterdam by way of the North Sea. In 1826 the North Holland Canal offered an easier access to the Dutch ports. However, with the development of shipping industry the dimensions of this canal become inadequate. To enhance the development of Amsterdam and neighboring cities, the North Sea Canal with about 230km in length and 7m in depth was opened as an international ship canal connecting the Rhine,Amsterdam and the North Sea in 1876. The effect of the new canal on the commerce of Amsterdam became tremendous[15),16)].

Before that, in 1862 the Rotterdam Canal was built to connect Rotterdam and the North Sea[17),18)]. To secure the canals entrance, the Schveningen and Ijmuiden ports were built at that time as the first outer ports facing the North Sea.

In Japan, after the Meiji Restoration, a type called modern canal was introduced by Dutch engineers, namely C.J. Van Doorn, J. de Rijke and others who were so-called o-yatoi-gaijin or foreign employees invited by the Meiji Government. No sooner had they come to Japan than they planned and built many canals, namely Touna and Kitakami canals in the Nobiru Port (1874) near the Teizan Bori canal afore-mentioned, a small canal around the fishery port zone of the Nakaminato port in Ibaragi and the Tone Canal (1888-1890), a genuine long distance canal connecting Tokyo Bay and the Pacific via the Tone River. Width of these canals were 25~27m; these were similar in size to the canals in Amsterdam urban area which had been built in 1610's. They brought the traditional Dutch canal concept into Japan[17),21)].

The reason why the Dutch engineers eagerly stressed the canal as a transportation measure is that construction work of the North Sea Canal and the Amsterdam Port had just started as a national project at that time (1866-1872)[17)]. They probably believed that the same approach used in Holland would also be successful in Japan. **Fig.2**, shows Van Doorn's plan on the Nobiru port with canals and dams in Miyagi Pref. and the city view of Rotterdam in the 17th Century. They closely resemble each other.[17),20)].



↑ Rotterdam City with Canals in the 17th Century

The Plan of the Nobiru Port by C.J. Van Doorn →

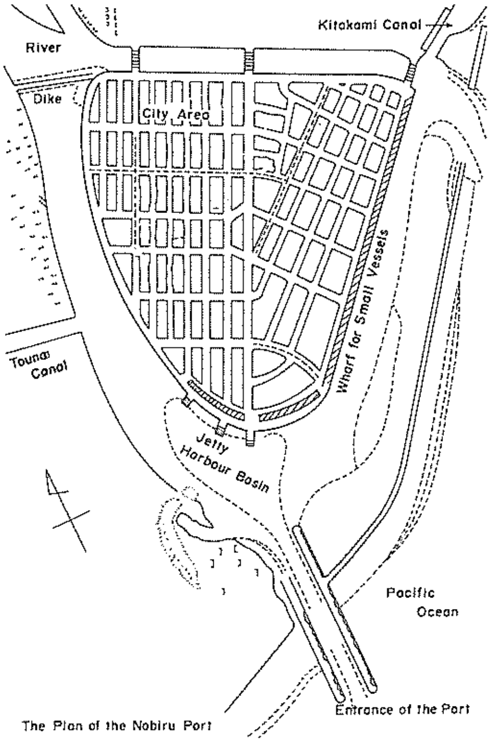


Fig.2 Comparison of two Plans: Rotterdam and Nobiru, a Japanese Port planned by C.J. Van Doorn, a Dutch engineer.

Unfortunately, all canals which they planned or constructed became useless due to modal change of transport from canal to railway and different features of waterways. However, an outstanding modern canal called the Biwako Sosui canal with 6 tunnels and 1 incline was constructed as a multi-purpose waterway, water supply for Kyoto City, hydraulic power plants and inland navigations by S. Tanabe in 1890. It is still used for watersupply in Kyoto city.

2.3 Limitation of Locks and Others

(1) Advent of Ship Canal

In the middle of the 19th Century, a new concept called ship canal had appeared.

Important canals, where a large traffic was expected, would be equipped larger locks. It served for ocean going vessels. There are two concepts related to ship canal. One provides access to deep sea harbours or in connecting such as the Manchester Canal opened in 1894, and the Amsterdam Canal. The other are international waterways such as the Suez Canal, Kiel Canal, St. Lawrence waterway, including Welland Canal and Corinth Canal.

Ship canal locks needed sufficient dimensions to accomodate great modern vessels and quick transit; this created many issues which had to be solved.

(2) Limitation of Traditional Locks

Prior to the advent of roads and railways, modern canals were first introduced in the late 18th Century, and played an important role for developing inland transportation network in Western countries through the first third of the 19th Century.

The reason why the ordinary canals had been developed was that its technologies were comparatively simple and acceptable in places where estuaries and deltas existed. Generally, the scale of a typical canal has remained constant since medieval times for transit of small ships or barges. As for lock canal, following disadvantages arose.

① Rise of Locks

Generally speaking, the larger the locks, the greater rise they are given, but for canal locks the normal rise of lift varies between 4ft. and 10ft., about 7ft. being a very common figure for English canals[3].

According to a paper, "Des escluses de faible hauter aux ouvrages de franchissment des grandes chutes (From Low Waterhead Canals to High Waterhead Canals)" by H. Donau and others, there has been an empirical limitation of waterhead (rising) for traditional lock canal based on French experience: it was less than 5.5m. They said also that a decision of the first PINAC Congress in 1885, which stated that a waterhead of any lock had to be less than 5m to ensure the safety of structures[4].

This came from the strength of wooden and masonry structure itself.

② Limitation of Graduant

In an ordinary sluggish waterway the distance between individual locks are adequate. The minimum desirable distance apart is 1 in 100 using a rise of 9 ft. But on higher ground, a difficlty arises in that locks are placed close together. In many cases summit of waterway must be steep rise in the route profile. Still greater slopes up to 1 in 10 can be obtained by use of staircase flights, but it is impossible for fullsize vessel to pass one another economically[3]. Steep slopes, especially long ones, therefore require special treatments or ideas.

③ Lockage Transit Time

So long as the lock chamber was small and flights were not so many, the traditional lockage system was effective. However the larger the chamber and, more flights, the more the time required for transit. Large ships could not bear it due to economic reasons.

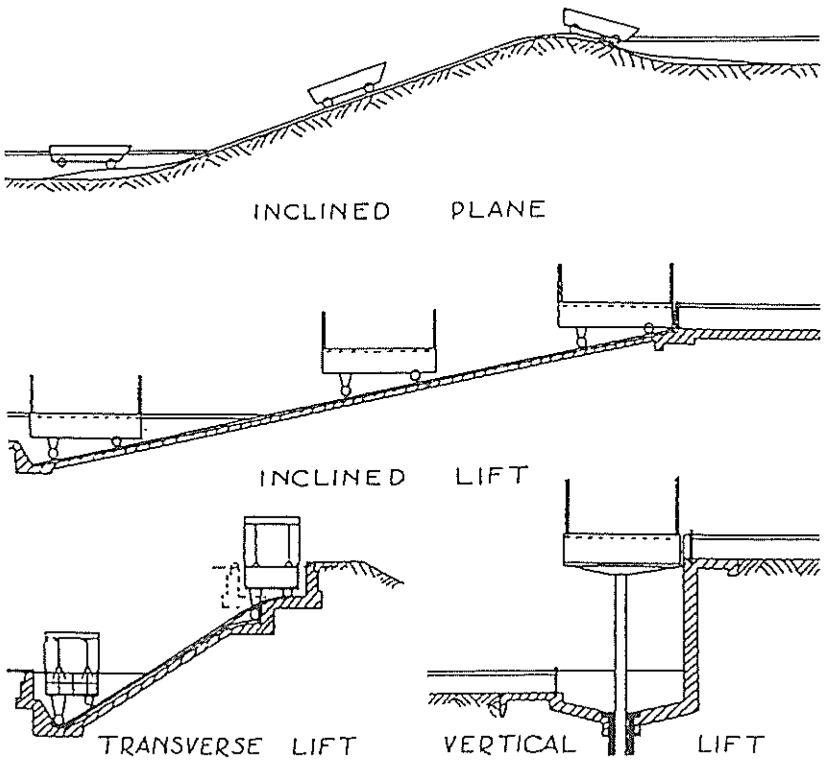


Fig.3 General Description of Lift

(3) Lift Canal

To overcome steep slope, another idea has existed as an alternative to the lock canal. There are four type lifts, namely inclined plane, inclined lift, trans-verse lift and vertical lift[3]. Water filled tank vertical lifts was introduced at the end of the 16th Century for lifts of the order of 20m, where there were water supply problems[22].

The first vertical lifts of any importance were built at the end of the 18th Century and in the 19th Century. Their lifts are still limited some 30m.

Recently, ship lift have been built for lifts usually greater than 30～40m and for large size vessels (1,350ton and over). They are always more expensive than locks, both in cost of construction and inoperation and maintenance. Accidents have concsequences far more severe than in the case of lock canal[22].

3. Difficulty of Isthmian Canal Project

3.1 Identification of Preferable Canal Route

From the beginning of the Spanish era to the middle of the 19th Century, expeditions and surveys had been made to find the most appropriate isthmian canal route, and al-though the outline of the Isthmus was taken note of, it had not been able to be found. Because, the alignment of canal must be more graduant unlike roads and railways, and it was difficult to find such a alignment.

Owing to Spanish expeditions, up to the 17th Century, four regions, namely, Nicaragua,Panama, Teuantepec and Darien came up as potential regions for canal alignment, and they made the first map of Central America in the 17th Century in the world (**Photo.3**)[11),23)]. Unknown deathly fevers took their toil on those who tried to venture into the Isthmus and their reconneissance was a kind of difficult art.

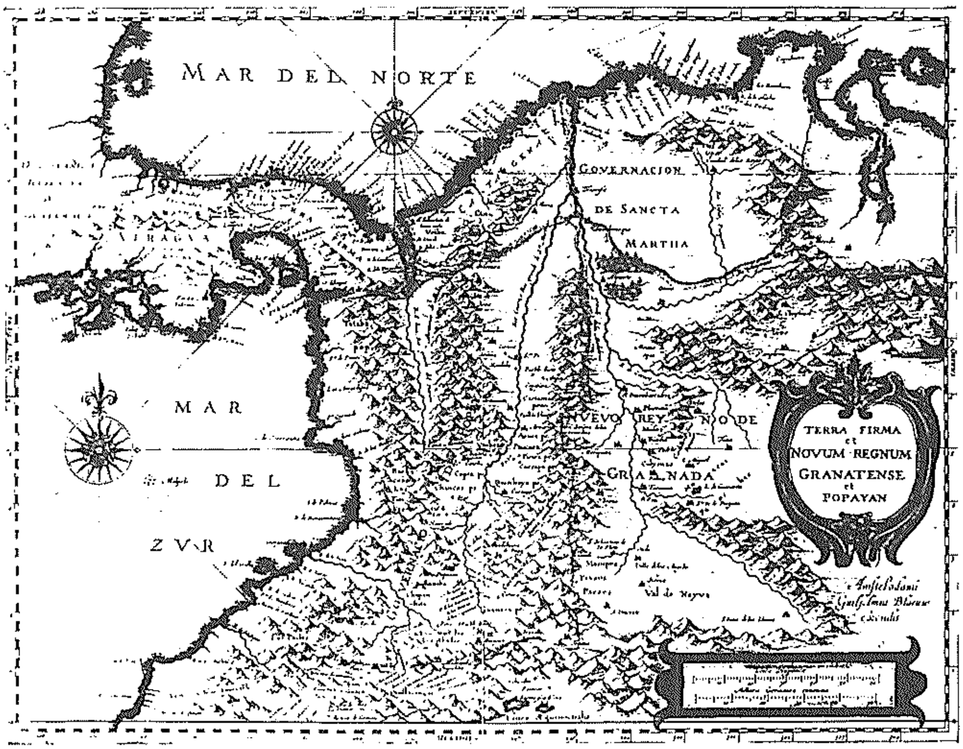


Photo.3 Isthmian Map published in Amsterdam about 1630
(By Courtesy of the Panama Canal Commission)

The deeper the jungle, the larger the topographic measurement errors.

Identification of preferable alignment had to wait until the latter half of the 19th Century.

In the beginning of the 19th Century, Alexander Von. Humboldt surveyed in the Middle and South America, and advocated the necessity of transisthmian canal. He suggested for the first time that a scientific method should be applied to obtain accurate measurements of all potential canal routes so as to compare them with one another[24].

Before the middle of the 19th Century, nobody was able to measure accurately and to find specific alignment without modern topographic measurement. It had taken about 3 centuries before the Panama route was decided as the best of all routes.

3.2 Labour Power

A canal, even if it was small one like a ditch, for its construction needed a tremendous amount of labour before the Industrial Revolution. For instance, the Brieare and Langue doc canals in 17th Century needed 6,000 and 8, 000 soldiers, respectively.

The availability of labour was also a problem in the regions. The reason why Spanishkings, the richest and most powerful rulers in the world, had been unable to build an isthmian canal was due to a shortage of labour. The regions of the New World dominated by Spain and Portugal were sparsely populated.

According to the study by G. Mack, the population of Panama in 1607 was only 5,650 including slaves and children, and in 1904 when the construction work of the present Panama Canal started the population, including neighboring regions, was 35,000[12),25)].

The low population kept isthmian canal project as a dream for long time.

Furthermore, in the ishtmian route hard rock and the huge amount of soil were obstacles far beyond their man-power. Until the advent of excavating and dredging machine, dynamite invented by A. Nobel in 1867, nobody could build the Canal.

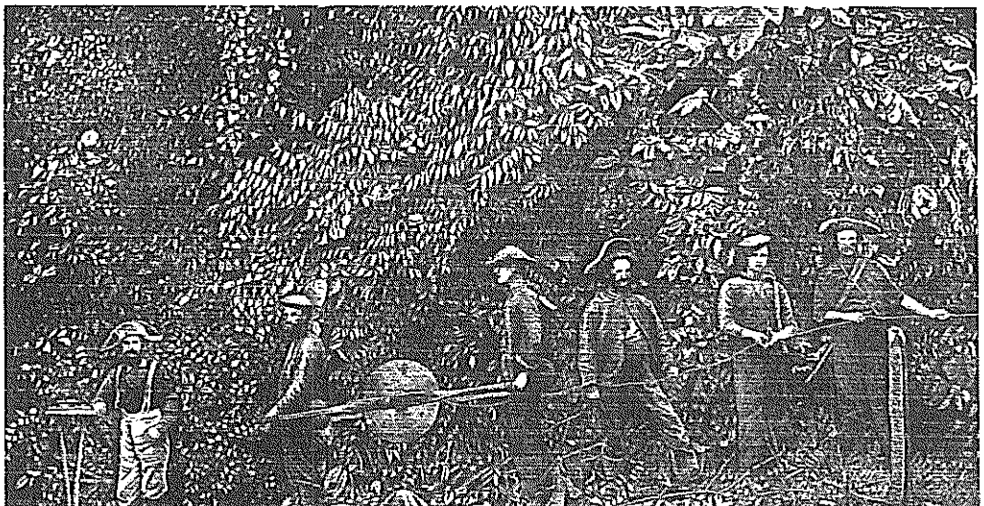


Photo.4 Difficult Expedition of the U.S. Navy in Darien

3.3 Tropical River and Mountainous Routes

Unlike Eropean rivers, currents and water levels of tropical rivers in Central America drastically change between the dry season and rainy season. For example, according to a survey by the U.S. Navy's expedition in 1870~75, in rainy season the Chagres River in Panama water surface rose 1m to 9~12m within a few hours in case of rain[26].

As streams generally run into mountainous valleys in the Isthmus, they are rapid.

The lock canal system born in Europe was for sluggish streams, so it was inadequate for tropical steep rivers. It was impossible to control the streams by traditional European locks or sluices throughout the entire a year without modern dams.

Technology for building concrete gravity dams for these tropical rivers did not emerge before the end of the 1880's[27]. Hence, no one was able to build a transisthmian lock canal before the 19th Century.

4. Key Ideas and Technologies for realization of Isthmian Canal

4.1 Multi-stairs Lock Canal

Any isthmian canal could not have been realized without technologies and ideas invented in the 19th Century.

The first was a device to overcome large waterhead by stretching traditional masory locks. The device appeared in the Caledonian Canal in the U.K. in 1822, and the Welland Ship Canal in Canada in 1829: the former was a cross-country canal between the Atlantic and the North Sea, equipped with 29 masory lock chambers with wooden and partialy cast iron gates to transit the U.K. navy frigates over 32m of height of the lake surface (**Photo.5**), and the latter was equipped with 39 small masonry locks with wooden gates to transit 170ton sailing vessels overcoming 100m of waterhead of the Niagara Falls[13),28)].

The secret of success was to build a series of same sized locks by several hundreds of masons, to make devices for prevention of leakage and subsidence, and to formulate water suppying system[13].

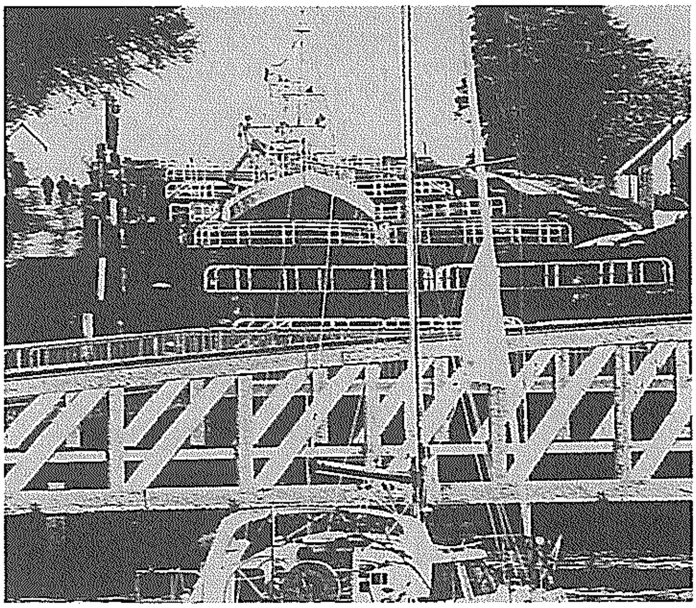


Photo.5 Typical Staircase Lock Canal
— The Caledonian Canal (Neptune's Staircase) —
(By Courtesy of A. Nagai)

Table.2 Plans of Ship Canal which influenced the Panama Canal in the Modern Age

Year/Planner	Site	Characteristics	Scale of Locks
1829 W.H. Meritt	Canada Welland[28]	The first multi-stairs lock Canal,100m of waterhead	①33.5m,②Width 6.6m ③Depth2.4m,④39locks
1838 N. Garella	Panama[29),30]	Combined 5,350m tunnel and 35 locks, Length 54.7km	①Width20m,②Depth3.6m, ③17locks (Atlantic)&18 locks (Pacific)
1845	Welland[28]	The Second Generation of the Welland Canal	①45.7m,②Width8.1m, ③Depth2.7m,④27locks
1850 O.W. Childs	Nicaragua[29),30]	Length of waterways 290km, width of waterway 15m	①76.2m,②18,2m③5.2m, ④34 locks
1869 Lesseps	Suez[35]	Length of waterway: 164km, Width: 22m, Depth: 7.5m	
1870 U.S. Navy	Panama & Others[30]	Length of waterway (Panama Canal): 67.1km, Width: 18～22m, ③8.6m,④24locks Waterhead each lock 3.1m	
1876 de Lesseps	Panama[30]	Panama Sea Level Canal Length 73.2km (the first plan including 7,720m), Width 20m, Depth 8.5m	
1887 Gov. of Can,	Welland[28]	The third Generation of the Welland Canal	①82.2m,②13.7m,③4.3m, ④26locks
1888 de Lesseps	Panama[36]	Level of artificial lake 43m Lock Canal	①180m,②18m,③10locks
1893 D. Adamson	Manchester	From Estuary of Mersey R. to Manchester Port, Length: 57km,	①L.183m,S.107m,②L.20m, S.14m③7.5m,④5locks
1898 French Gov.	Panama[36]	Two lane lock canal with small and large chamber	①225m,②L25m, S18m,③10m ④4stairs, 2lanes, 8locks
1901 Walker Com.	Panama[36]	The first concrete plan by the U. S. Gov.	Basically same scale of the former French plan.
1908～14 ICC	Panama[37]	1908 by request of Secretary Defense, the present lock size was decided.	①315m,②33m,③12.2m④2lanes, 3stairs, 12locks

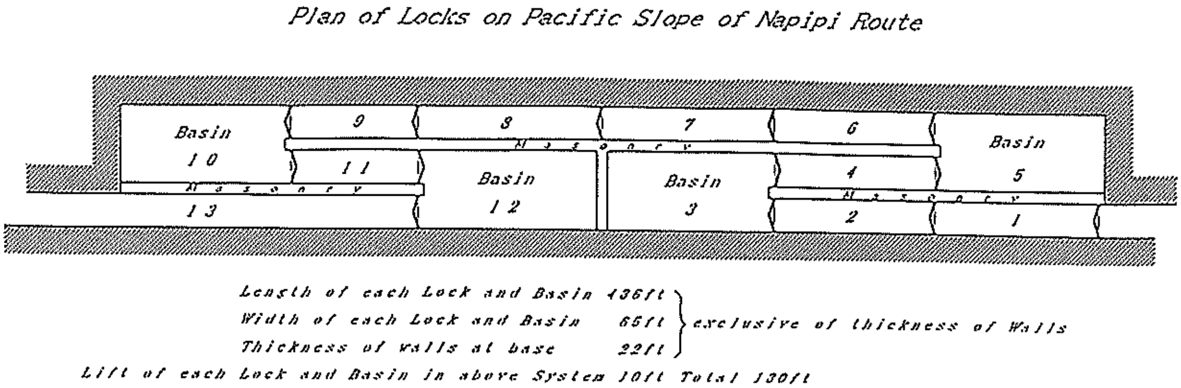
Remarks : ①Length of Lock, ②Width of Lock, ③Depth of Water, ④Number of Locks

This idea made possible the construction of a lock canal in a rapid stream like trans-isthmian canal. Two primitive isthmian canal plans, namely, a Panama canal (1838 : 35 locks) made by N. Garella, a French engineer, and a Nicaragua (1850:34 locks) canal made by O.W. Childs, an U.S. Army Colonel are shown in **Table.2.**

As the first concrete trans-isthmian canal plan, Garella depicted a figure stretching from the estuary of the Chagres River to Vacamonte, a waterway with 35 locks and a 5,350m tunnel[29),30].

In 1770, the year following the opening of the Suez Canal, the U.S. Army had tried comprehensive surveys and expeditons which aimed to find the most preferable alignment by way of comparing prominent routes with each other. After 5 years' endeavour, U.S.

Navy proposed three lock canals, Panama, Nicaragua and Darien, all were typical multistairs lock canal system. Proposed plans were;①Panama route connecting the Grande and Chagres rivers, a 67.1km length of waterway with 24 locks and a 580m viaduct to cross river bed of the Chagres river;②Nicaragua route connecting the Rajas and Grande rivers via Lake Nicaragua, a 292km length of waterway with 20 locks, 18~22m width, 7.9m depth; ③Darien in Columbia, connecting the Atrato and Napipi rivers, a 48.6km of marginal waterway with 22 locks and a 5,630m tunnel[31),32)]. As for the Darien canal, the lock system was a unique loop staircase (Atlantic side 12, Pacific side 10)[33)]as shown in **Fig.4**.



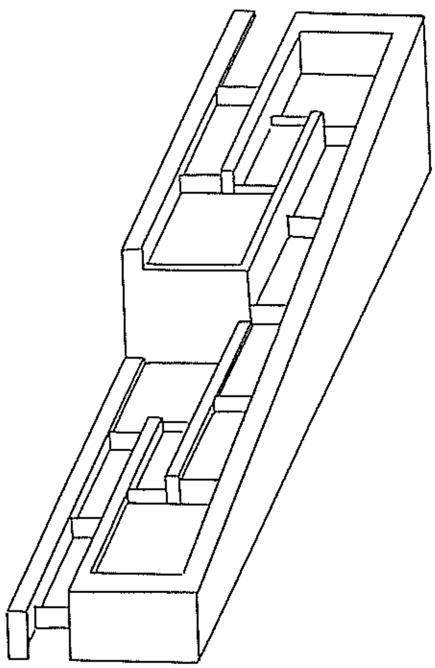


Fig.4 An Unique Loop Staircase Lock Plan in a Trans-isthmian Canal by the U.S. Navy (1870~75)

4.2 Steel Gate

In the latter part of the 19th Century a new concept called ship canal which serves to provide access to a deep seaport or composed of great international waterway was introduced.
The Welland, Suez, Manchester and Kiel canals were based on the concept. From the latter half of the 19th Century, depreciation cost of steam vessel became high compared with that of traditional sailing vessels, therefore, traditional cargo handling system in ports and harbours for sailing vessel, which had mainly depended on offshore transshipment to small barges to alongside handling without modern quays wall or wharves, became obsolete from the economic viewpoint[34].

For the same reason, these multi-stair locks that had appeared in Europe proved to be costly and inconvenient for transit of steam vessel. In order to save time and cost of lockage transit, following idea emerged; to overcome large waterhead with fewer stairs, new materials were required to reinforce the lock structure.

It is natural that in the course of incremental ship canal or development river canal for in rapid stream, they began to consider iron and steel as material for gates to bear the huge water pressure. The reason why they could use iron and steel for materials of gates was the great innovation of the steel mill through the Industrial Revolution.

Cast iron products had been developed in commercial form by an Englishman, J. Willkinson, in 1794. Cupola have been able to supply a great amount of gray iron melted as it is today. An innovative process that changed gray cast ingot to steel was invented by H. Bessemer and others in 1864. By the invention, cheap steel products spread throughout the world.

Following the historical development of iron and steel products, iron parts were first used in the gates of the Ellesmere Canal in the U.K. in 1793, and full armored gates appeared in the Caledonian Canal in 1920's[13),38)].

And in the latter part of the 19th Century, steel gates began to be used in advanced canals. A modified canal plan after the U.S. surveys was designed employing a rolling steel gate by A.G. Menocal, an American engineer. This might have been the first steel gate in the history of the trans-isthmian canal plans (**Fig.5**). In 1888 de Lesseps lost confidence in his sea-level canal and converted to a lock canal plan, then, requested Effel who had built the Effel Tower to design steel gate. However, the gate was never realized. Because Lesseps, company went bankrupt[39]

Steel gates made a larger waterhead of more than 5m possible. As for the present Panama Canal, 92 gate plates amounting to 60,000tons including intermediate gates were installed to overcome about 8~10m waterhead.

4.3 Topographic Survey

The modern topographic survey technology was invented in France in the beginning of the 18th Century. French territory was covered by a triangulation network. The technology had spread over Europe by the end of the century.

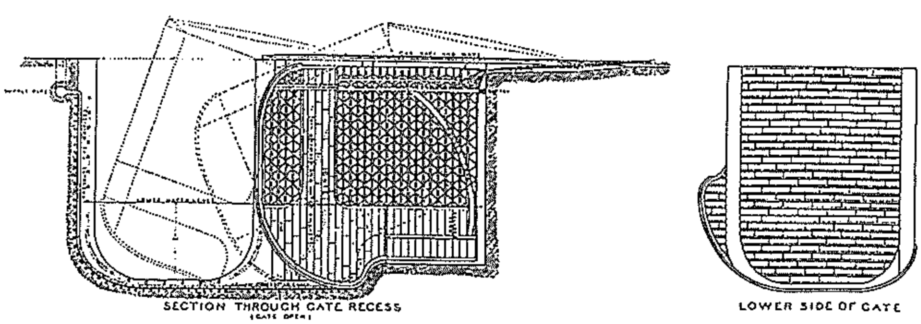


Fig.5 Menocal's Rolling Gate Plate

Table.3 Trend of Waterhead and Lock Size

Year	Name of Canal ◎Iron/Steel Gate	Waterhead (m)	Lock Chamber (m)		
			L	B	D
1497	da Vinch's Canal	2.7	29	5.4	?
1692	Langue doc	2.4~2.6	35	6.3	2.4
1824	◎Caledonian Canal	2.2~2.4	55	12.1	6.1
1829	Welland 1st	1.8~3.4	34	6.7	2.4
1845	Welland 2nd	2.9~4.3	46	8.1	2.7
1870	◎U.S. Navy Panama	3.1	132	19.8	8.6
1887	◎Welland 3rd	8.6	82	13.7	4.3
1889	◎Lessep's Panama	abt.10	180	18.0	?
1987	◎Manchester	4.4~4.9	182	19.8	8.5
1901	◎Walker, s Panama	8.4~9.2	225	25.4	11.0
1908	◎Present Panama	8.2~9.9	305	33.5	13.0

Since steep mountains and dense jungle covered the Isthmus, explorers had kept their distance. As a result, it had taken about 350 years until the most preferable alignment was decided in Panama in 1979.

The first modern topographic survey in the Isthmus was executed by J.A. Lloyd, an English engineer in 1829[30]. In 1847, the Gold Rush caused a boom and a large transmigration from east to west occurred. To cope with the transportation demand, the Panama Railroad Company was estabished as the first trans-oceanic railway in 1849.

At the request of the company, two engineers, James L. Baldwin and G.W. Hughes surveyed the Panama Isthmus, and found the lowest point to be 84m height in a valley called Culebra in 1850, but later it was discovered that the Culebra is the second lowest point in the Central American Isthmus following the 47m valley in Nicaragua which O.W.Childs had discovered[40]. F.M. Kelley, an American businessman tried expeditions to San Blas, the narrowest point of the Isthmus in 1851. Through these surveys modern apparatus such as level, chains, altimeter, plane table began to to be used[41]. In 1869, the same year the Suez Canal was opend, the U.S. Government instructed the Navy to find the most preferable route in the Central Isthmus. After 5 years of difficult work, the first accurate topographic survey was completed all over the Isthmus by the Navy. As a result, it was noticed that no route had potential except Nicaragua, Panama and Drien (Atorato and Napipi)[30),31),42].

The International Congress on Study of the Isthmian Canal (Congres Internationald, Estudes de Canal Inter-oceanique: hereafter the Paris Congress) advocated by de Lesseps was held in Paris 1879. In the congress, they compared nominated routes with each other and chose the Panama route as the best of all. This was a memorable congress which put an end to the longstanding debate over the best route[43),44].

During World War II, they had been able to obtain topographic data by the aid of airplane without any difficult reconnaissance.Examining the data and the past explorers' surveys, 30 routes that should be evaluated were found[45].

4.4 Artificial Lake Concept

An outstanding revelation was the idea presented at the Paris Congress 1879 by A.G. Lepinay, a French engineer. This was to build an artificial lake, almost the same as Gatun Lake at present, for the purpose of saving dredging and excavating cost, flood control of the Chagres river and the saving of lockage water[43].

Conversely, also at the Paris Congress, the U.S. Navy engineer team proposed an expensive lock type canal with a viaduct to cross the flooded Chagres River (**Fig.6**).

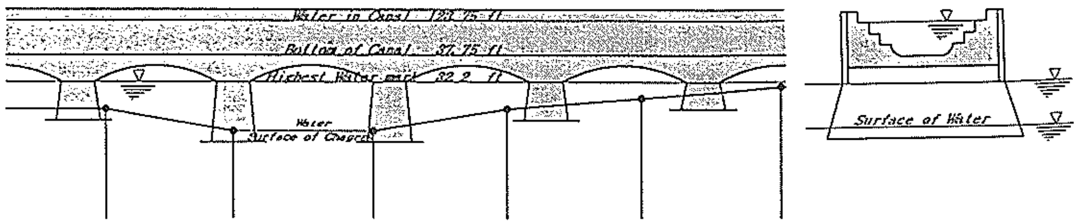


Fig.6 Proposed Viaduct in a Panama Canal Plan by the U.S. Navy (1870~75)

The surface of summit of water for their canal was deemed 37.7m, based on the highest water level of the river, 10m. This viaduct type had been a widely used idea in advanced canals such as the Ellesmere and Gota canals[16),38)]. Later it was found that viaducts became expensive for large ship canal waterway, hence, 15 years later, the concept of the lake was reevaluated by the new French company and 25 years later, the ICC borrowed the idea and finally came to realize it as Gatun Lake as shown in **Fig.7**.

Without this concept, the present Panama Canal would not have been possible.

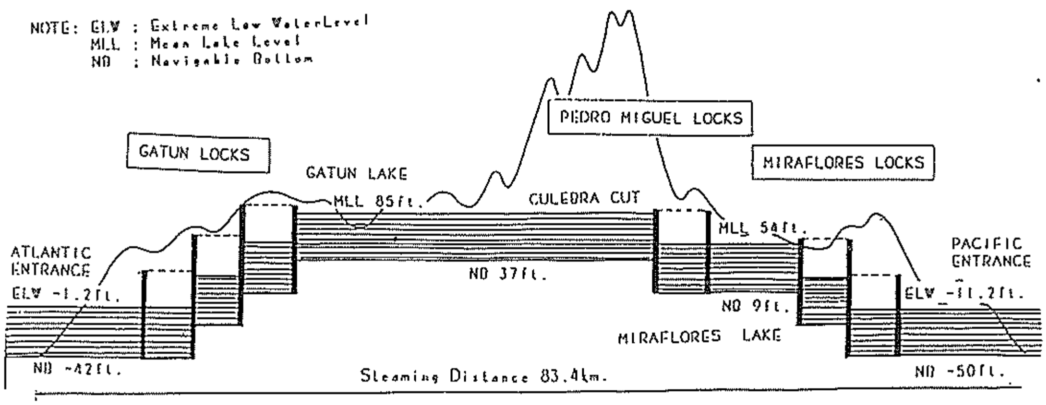


Fig.7 Longitudal Cross Section with the Man-made Lake (the Present Canal)

4.5 Geo-technologies

In the middle of the 19th Century, no one could calculate the amount of excavating volume for any isthmian canal route. Geological survey was first started by the U.S Navy in 1870 and L.N. Wyse's survey, a French Lieutenant in 1877, and the technical development was remarkable as the years passed. The U.S. Navy team made longitudinal cross section of each alignment for comparison. Wyse's survey estimated rough soil and rock volume[46)]. A detailed excavation volume in the alignment of de Lessep, s sea-level canal was estimated by J.I. Dingler, a French engineer in 1885[43),47)].

The survey of the Walker's Commission produced detailed geological maps in the Nicaragua route in order to compare with the Panama route which was offered by the new French company[48)].

The U.S. inherited the work. The basic technology relating excavation and dredging was not so different from that of the French except the capacity of machines and the systematic approach. But, the quality of the survey was different: the U.S. executed 5,073 borings and the French only 605. The U.S. engineers found that the Cucaracha layer was one of the softest in the world, and they developed geotechnology through the work of maintenance[49)].

In 1970 the Interoceanic Canal Study Commission Report tried to present a standard called JAX 46 on slope stability by layer, by route[50]. The PCC had already started a land slide control project: apparatus were varied in the slope in order to get the information on the relation between stress and strain of entire mountains.

G. Berman, the chief engineer of geo-tech. said that PCC had already obtained the data and program and that by using it, the analysis of design slope is possible with high accuracy. The steeper the the slope, the more frequent sliding occurs. He said that there are many options to deal with slope, and the solution will be in the debate of economics.

4.6 Mass-Concrete Structure

Portland cement was invented in the U.K. in 1820's, and, it quickly spread to all land facilities. But, a little time was required before it could be used for submergedstructureslike the Panama Canal. Three problems to be solved were as follows.

The first was erosion caused by sea water, the second was design of concrete structure. And, the third was that an augmented lock chamber became necessary supplying plenty of water and much time for filling/discharging.

As for the first problem, when portland cement was introduced at the Dover Port of the Admiral Pier in 1847 for the first time, a countermeasure covering the surface of concrete blocks with granite around the tidal range was taken[51]. Hereafter, this method was applied until the beginning of this Century. Regarding the first prototype of the Panama Canal, the same measures were proposed in the Walker Report in 1901[48]. But, in the final design of the Canal approved in 1908,these measures were not applied[51]. The quality of portland cement and skills had been on the way of improvement at that time. Standards of cement usage for the Canal construction was made by ASCE and the isthmian Canal Commission (ICC). The problem could be solved at that time.

The Second Problem was how to build large mass-concrete strucures. Block type structure like Admiral Piers had spread to many world ports, namely, Arderney(1872), Karachi (1860), Madras (1877~85) in the U. K. and Yokohama (1889~93) in Japan[51]. In the latter half of the 19th Century, using cement for maritime structures was difficult work.

In the case of Arderney, the construction work was given up after a 30 years struggle against rough waves, while in Yokohama, many concrete blocks were cracked and the work had to be suspended for a

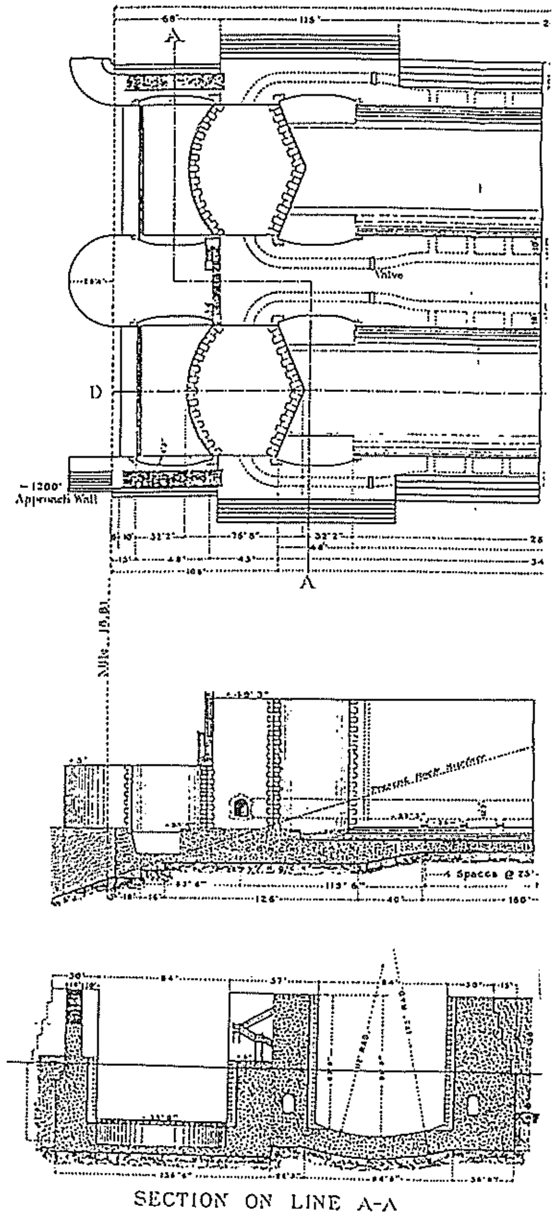


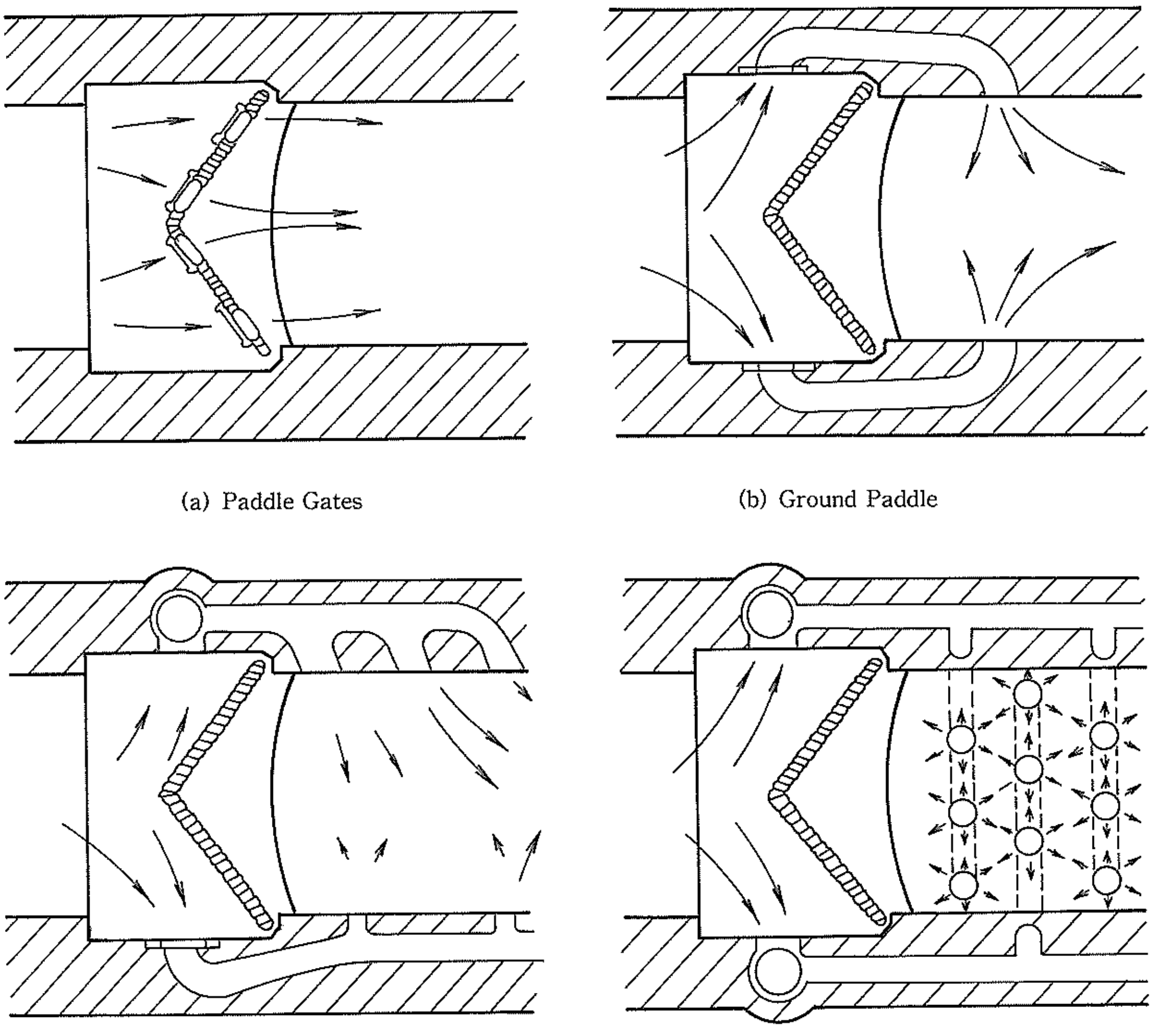
Fig.8 The Prototype of the Lock (Walker's Commission Plan 1901)

while. Basically, block structures are weaker than gravity type mass-structures. However, development of gravity type structure had made slow progress due to immaturity of skill and design arts.

Considering caisson type quay wall or breakwater, the first plan was proposed in the study for the aforementioned Dover port as an alternative in the 1840's, but it was not realized. The first caisson appeared in the Zeebrugge port for a new breakwater with 4,500 tons of metal formed caisson. The first concrete caisson was tried at Aberdeen in Scotland. Genuine caisson quay walls appeared in the Kobe and Surabaya ports in the beginning of the 20th Century[52].

As for gravity concrete dams, more than 50 years had passed before the advent of the 30m high dam. When the concrete locks and dams of the Panama Canal began to be constructed, the height of the tallest dam in the U.S. was still only 90m[27].

For lock wall of the Panama Canal a concrete gravity section was adopted(this did not depend on reinforcement for stability, but certain subsidary parts such as culverts were reinforced.



(a) Paddle Gates

(b) Ground Paddle

(c) Longitudinal Culverts

(d) Spur Culvert

Fig.9 Historical Development of Filling and Discharging System of Locks

4.7 New Filling and Discharging System for Large Lock Chamber

As for filling and discharging water system for traditional locks, small apertures called paddle gates as the oldest pattern had been equipped on the wooden miter gates since medieval times (**Fig.9 (a)**). However, so long as the chambers were small the system was effective. The larger the chamber, the time for filling or discharging became a problem until a new idea emerged to equip two by-passes connecting between the upper and lower chambers called a ground paddle.

This system was fashionable for the canals during the Industrial Revolution: the Caledonian Canal employed this system (**Fig.9 (b)**).

By that time, coping with incremental vessel size, it was feared that the current through the paddle gates or the ground paddle would have beat vessel against wall or the oppsite lock gate.

Hence longitudinal culverts and many small holes were equippid along both side walls.

The prototype of the Panama Canal employed this system (**Fig.9 (c)**).

As for the present Panama Canal, the longitudinal culverts system was inadequate because it was presumed that the system took tremendous time for filling/discharging. Hence the spur culvert system which consisted of many small holes over the bottom floor of lock chamber was proposed (**Fig.9 (d)**).

The present Canal was designed in order to transit within one hour in 1908. That is, time for filling/discharging for each chamber of 90,000m^{3}had to be within 7~8 minutes. Hence the diameter of main three culverts in the walls were 31.94m^3 each, which were the same scale of railroad tunnel in the U.S., and branch culverts under the bottom were 3.8m^3, which could pass a coach easily and 114 holes over the bottom floor.

4.8 Excavating Engineering and System

Until the middle of the 19th Century, a technological system for mass-excavating had not yet been established; it was a headache to excavate by labour intensive work.

The advancement of excavating engineering is as follows.

- Railway released mankind from the labor intensive work of material transportation.
- Excavating machines emerged in the latter half of the 19th Century. These were widely used in the work on the Suez Canal.

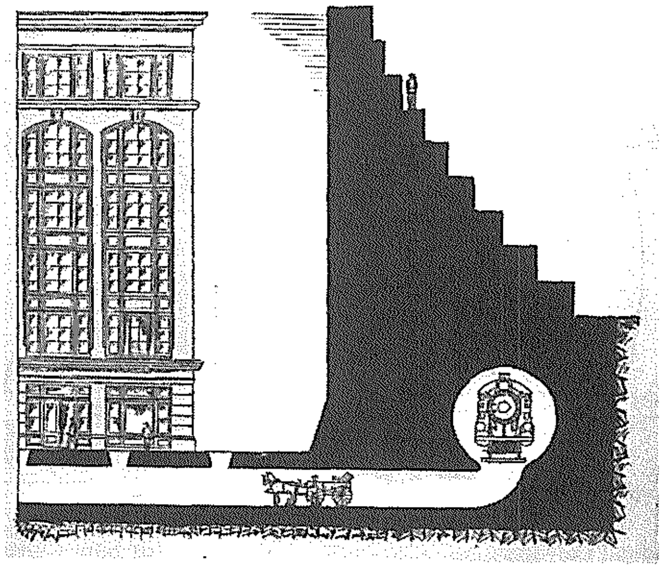


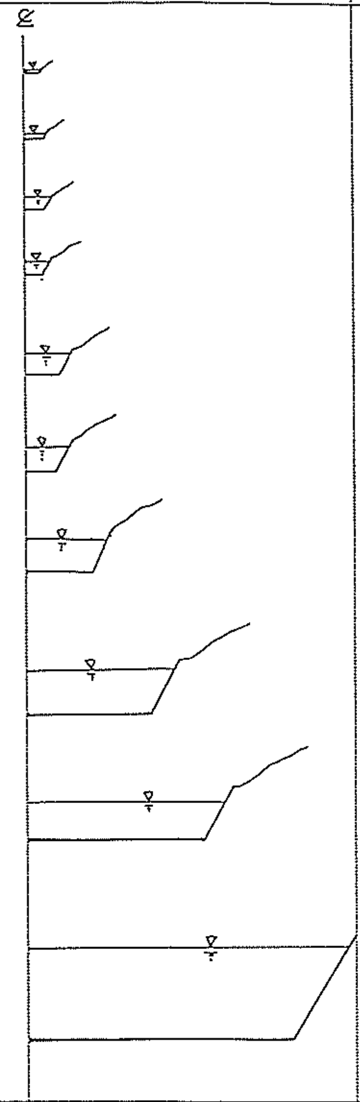
Fig.10 Section of walls and Culverts of the Panama Canal

●Dynamite was invented by Nobel in 1867.

The difference between the U.S. and French engineering came from the ability of machines and system engineering. The maximum excavating volume per year was 12.7 million m³ in 1888 during the French era. This was lower than the U.S. average during the construction period, and also lower than the highest record per month of the U.S., 15.5 million m³in May 1909[55),56)].

The secret of success of the U.S. was a unique excavation sytem combining railway networks and excavators devised by J. Stevenson, the chief engineer of the ICC[47),56)].

In 1970 the InteroceanicCanal Study Commission stated that for route 10, a sea-level canal, an excavating plan with 2,800 heavy machines would be introduced to achieve 1,477 million m³ in 10 years. This means that the



	Cross Section	W (m)	D (m)
1605～42 Briare Canal		12	1
1666～62 Langue doc Canal		19	2
1843 Garella's Panama Canal		17	4
1850 Childs' Nicaragua Canal		15	5
1859～69 Lesseps' Suez Canal (Openning)		22	8
1881 Lesseps' Panama Canal (First Plan)		24	9
1901 Walker's Commission Plan		46	11
1914 ICC Panama Canal (Openning)		91	13
1960～70 Present Panama Canal		152	14
1983 Nagano's Plan		200	33

Fig.11 Trend of Cross Section of Waterway relating Major Canal Plans

capacity of modernized exca-vating system is about 10 times larger than that of the work executed in 1904～14.

It may be possible to develop a system that excavates more than 100 million m^3 per year for the new Panama Canal. The Shin Kansai International Airport executed 0.2～0.3 million m^3 per day. As shown above, excavating technology for the future may already be developed at present.

4.9 Planning of Waterway

From medieval times up to end of the 19th Century, dimensions of canal had been determined empirically. The cross section of a typical river canal in medieval times and section of the latest canal are shown in **Fig.11**. The traditional canal had an empirical ratio between width and depth of 3: 1 to 4: 1.

From the end of 19th Century, the decision for cross section has become a little more scientific. In the case of ship canals which have been built in the 19th Century, these sections have been defined by referring to augmented vessels[48].

In the Paris Congress of 1779, a standard cross section which was the same used in the Suez Canal was applied to compare trans-isthmian canal plans[48]. In the Walker, s Report 1904, the Lloyd Register was used to decide a standard size of ship for the prototype of the Panama Canal. And a rule for increment of width of waterway was taken into consideration to cope with curvature. The width of waterway on the first prototype, 300ft., was adopted to represent 3 times the width of the maximum sized vessel[48]. The ratio of width and depth was 7.5: 1.

From 1923～38, to secure wartime security land slide zone, narrow points at the Culebra were widened to 5～700ft.. And, partial improvement of the channel was executed with consulting pilots of the Canal. After World WarⅡscientific model tests and simulations were executed in the Governor's Survey 1947[57]. The waterway of the Culebra Cut was widened from 3～500ft.during the 1960's. The depth of water was checked by squat and seiche effects[57].

The Inter-oceanic Canal Study Commission executed the same survey in 1947. In 1972 effect of squat was checked using a real ship test[58]. A plan of the Culebra Cut Widening of 1982 introduced a model test, simulation and pilot hearing.

This is the chronological trend of determination of waterway.

The features of the present Panama Canal are shown as follows.

Table.4 The Features of the Present Canal

Length of Waterway (Deep Sea to Deep Sea)	83.4km
Width of Waterway	150～305m
Number of Lock (Chamber)	3 (12)
Length of Lock Chamber	305m
Width of Lock Chamber	33m
Depth of Waterway	12.8m
Total Excavating Volume (by ICC : ～1915)	177.5 million m^3
Excavating Volume by French Co.	59.7 million m^3
Concrete Volume	3.7 million m^3
Construction Cost	375 million $
Amount of Water Usage/one Transit	0.197 million m^3
Amount of Usable Water of Gatun Lake/year	about 4,700 million m^3

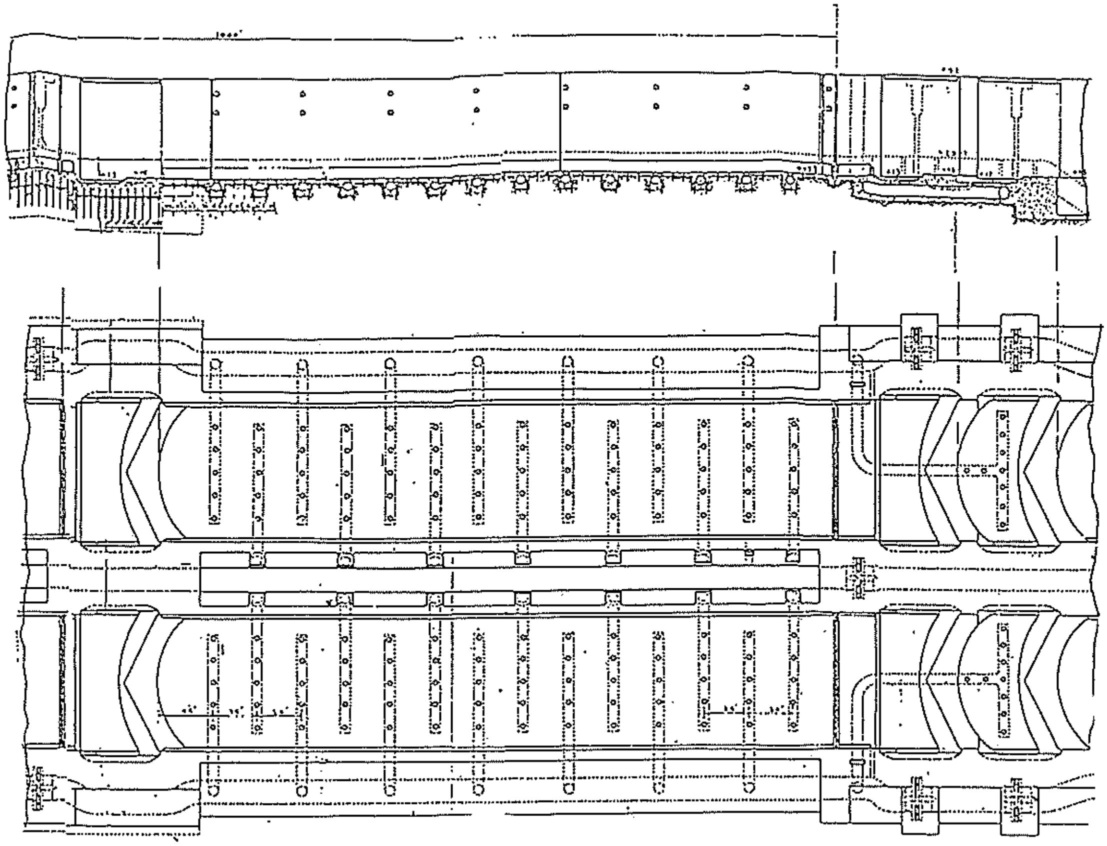


Fig.12 Profiles of the Present Panama Canal Lock

5. Issues for the New Panama Canal in the 20th Century

5.1 Relation between vessels and the waterways

Through the history of trans-isthmian canal plans, there has been one on going controversy. This is the sea-level plan vs. locks plan, because only 5 alignments in Panama (Route 10～14) out of the 30 along the Isthmus are possible for a sea-level type of canal.

In the course of history, the controversy has arisen four times, namely, the Paris Congress in 1879, the debating of ICC relating the basic design of the present Canal in 1908, the Governor's Report in 1947 and the Report of the Interoceanic Canal Study Commission 1970[45),46),47),48),49),50)]. Except in the debate of 1906, sea-level types have won out, but the actual execution of sea-level works has not yet been started.

From 1930's, in order to transit gigantic warships or aircraft carriers and from 1970's to transit huge super tankers, large lock or sea-level canals have been proposed until now. The proposed canals in the 20th Century are shown in Table-3 and an incremental relation between vessel and canal of each era is shown as follows.

a) Comparing canal plan with vessel size of each era, a series of cross sections of channel "S" (multiplied minimum width by depth) and of vessel size "V" (multiplied width by draft) and time "t" (1800=0), some incremental formulas are obtained as follows.

Canal Size (1843-1892) : $\log S = 0.0146t+1.12$ ($r=0.986$)
All Vessel (1831-1962) : $\log V = 0.0106t+1.11$ ($r=0.939$)

b) The age of sailing vessels was over by the 1970's. The Suez Canal was said to be the first canal which was designed only for the steam vessels. Observing the series of incremental canal plans of the isthmian canal, it was found that these were also considered for steam vessels. Sailing vessels which were developed during the 19th Century had not influenced the Central American Isthmian Canal.

c) From Fig.-12, we could observe that the scale of the Panama Canal completed in 1914 was far beyond the line of the formula, that is, a considerably larger size was adopted at that time.

d) Observing the plans after World War II, we found that the U.S. changed its policy on canals 「Interoceanic Canal Study 1970」 : a canal plan is not deemed as a military entity but as commercial route for transit of super tankers. Before that plans were only for naval vessels.

5.2 Problem of Augmented Canal Project

As for a sea-level canal, the cost to be incurred for sea-level canal will be over 10 billion dollars at the present price value, considering 28 hundred million dollars in cost for the route 10 plan according to the Interoceanic Canal Study 1970, including excavation of earth and sand (rocks included) conveyance, abandonment, and related works[58].

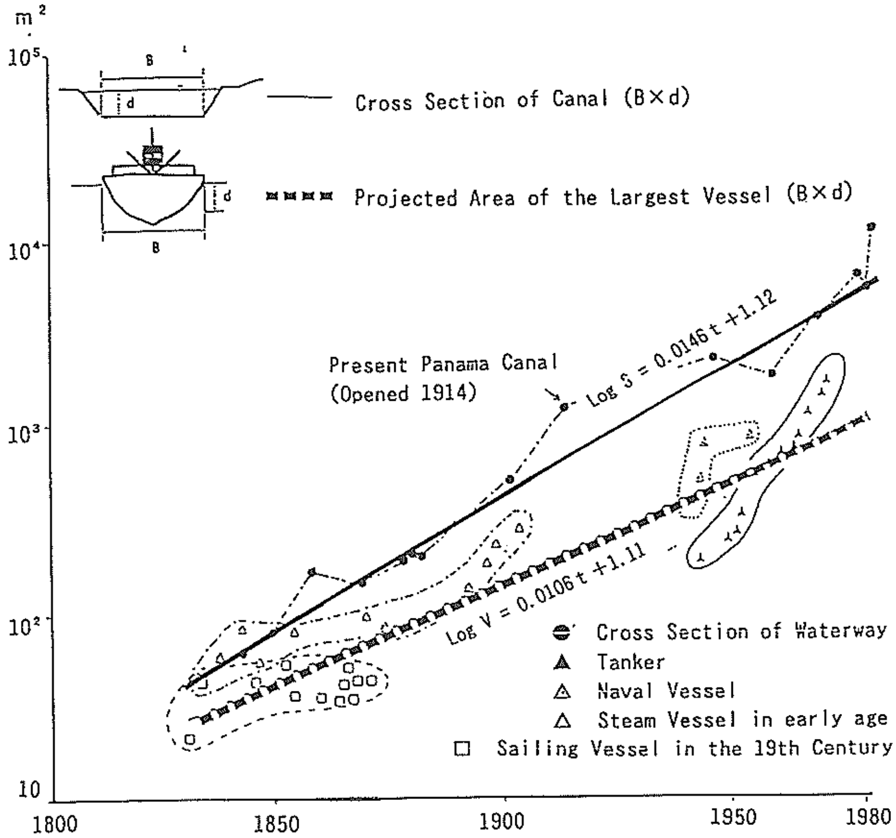


Fig.13 Relation of Augmentation between Vessel and Canal Waterway

Generally speaking, construction cost of sea-level canal depends on the excavating volume, hence, it depends on topographic conditions of the respective canal.

The extraordinary cost for sea-level canal occurs due to the fact that excavation must be performed below sea-level in mountains. Furthermore, as for sea-level canal, it is difficult to trim the cost by ingenuity or device.

On the other hand, with the lock type of canal, some devices are possible with provided ideas. For example,

(1) With the present waterway, widening and increasing depth must be planned. By digging down along the present route of the Canal, costs can be reduce with some devices.

(2) To increase the water-level of Gatun Lake as much as possible. At least, by making small repairs for the exsiting locks, levelling up of water by 1~2 meters will be possible.

However, as for plans for large lock canal, a new problem came up; a super tanker loaded with a full cargo in transit, the ship can only move at a slow speed within a lock chamber as her force of inertia is very large. It will take more time than as in the present Canal due to slower speed and the longer lock. The lockage transit will be 2-4 hours per lock for the full cargo vessel of 150-170 thousand DWT to transit.

Therefore, by decreasing the number of locks, it is necessary to make the transit time shorter.

Table.5 and **Fig.14** Shows a comparison with the recomendable size lock by author and recent new Panama canal plans.

Table.5 Major Proposed New Panama Canals in the 20th Century

year	Name of Plan	Features	Scale
1931	Third Lock Project[59),60)]	Additional a new lane for transit of gigantic Warship: after beginning of World WarII, the project was stopped.	B①366m,B②42.7m,B③13.7m, B④6,B⑤3, B⑥55mil. m³
1947	Sea-Level Canal[45)]	A sea-level canal with almost the same alignment with the existing one.	A①42km,A②183m, A③12~18m,A④817mil. m³
1947	Terminal Lake[57)]	A lock canal converted from 3 to 2 stairs to save lock cost.	B①457m, B②61m, B③15.2m, B④4,B⑤2,
1970	Route 10 Sea-Level Canal[58)]	The last Goverment's plan for transit naval vessels. A sea-level canal plan 15km westward from the existing one	A①64km, A②168m, A③25.9m, A④1,428mil. m³
1970	Deep Draft Lock[58)]	A lock canal converted from 3 to 2 stairs	B①442m, B②48.8m, B③19.8m, B③4, B.⑤2, B⑥423mil. m³
1979	S. Nagano Plan[61)]	A sea-level canal for transit of super tanker	A①64km, A②200m, A③35.8m, A④1,940mil. m³
1981	Lopez & Moreno Plan[62)]	A lock canal proposed by Panamenians. double (large and small) lanes	B①427m, B②L57.9m, S22.9m B③L21.9m, S10.9mB④8, B⑤2, B⑥611mil. m³
1982	Vergara Plan[63)]	A sea-level canal proposed by Vergara	A①64km, A②450~500m, A③26m, A④2,415mil. m³

Author's Proposal	A shaft lock canal with side pond for Cape seze vessels	①360m,②50m,③18m,④2 or 4, ⑤1 or 2

〈Remarks〉
Sea-Level Canal: A①Length of Waterway, A②Width of Waterway, A③Depth of Water A④Excavation Volume (million m^3)
Lock Canal: B①Length of Lock Chamber, B②Width of the Chamber, B③Depth of Water in Chamber, B④Number of Locks, B⑤Number of Stairs, B⑥Excavation Volume (million m^3) L: large, S: Small

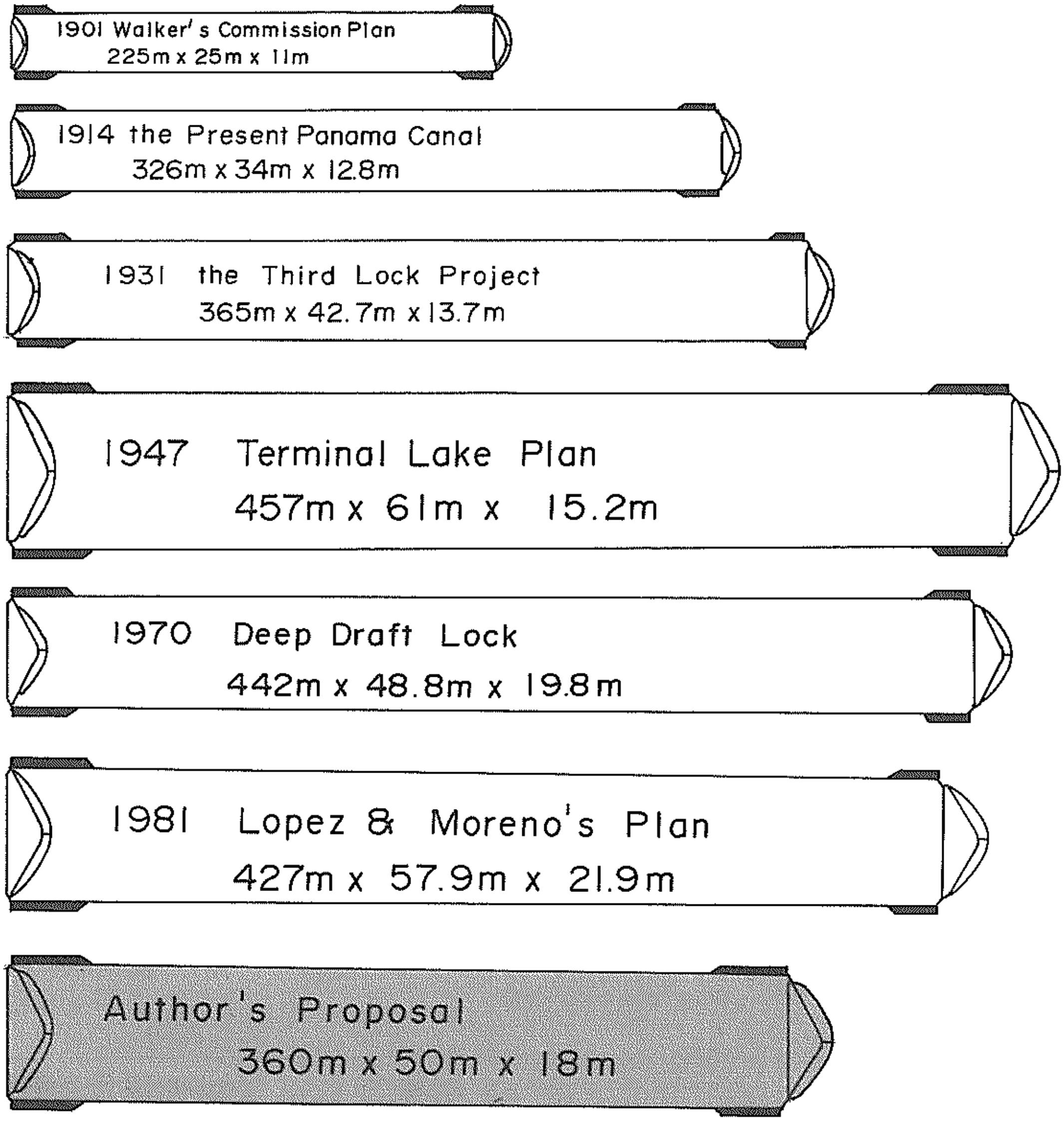


Fig.14 Trend of Lock Size of New Panama Canal Plans and Author's Proposal

3 stairs by locks up to Gatun Lake at present will have to be decreased to 2 stairs. or shaft lock. One lane will be sufficient for the time being, but it must be determined comprehensively by making a simulation, and hearing from experts in charge of works at locks of PCC.

Water supply is also a problem for a large or fewer stairs lock canal plan, however, it will not be critical. Water consumption per year depends on the number, size of vessels and on the combination of arrivals. It is, also, possible to save water by means of double lockage, which lift up and down 2~4 vessels at one time. The precise details will not be clear due to the complicated combination of premises, but it is sure that 1.3-1.5 times of additional water consumption for the new one lane will occur. It means that it is necessity to provide measures such as pumping-up, water-conveyance from other river systems, new dams and side pond, etc, as mentioned by Ropes Moreno's plan[62]. Air-lift method, which seem to be logical, has many technical problems. The most realistic solution is to provide side ponds beside the new lock. The side pond system has been widely used in Europe canals until now[64].

Fig.15 shows a water saving lock system composed of a shaft lock and side pond.

6. Conclusions

This paper described and analyzed the historical development of canal technology from medieval to the present Panama Canal and dicussed contemporary issues.

A) Traditional barge canal has been on the decline since the beginning of the 20th Century. Although the canals built in the 19th Century have declined in Europe and the U.S., they still provide services as a complemetary transportation system and beautify landscape surroundings and neighboring towns.
As for Japan, traditional canal and inland navigation from medieval times partially remained as a subsidary system until the 1960's before the road network developed.
But, no canal remains as a trasportation system at present.
Hence, inland transportion mainly has been depending on road transportion during these three decades, problems such as an pollution, traffic jams have become serious. From the long historical viewpoint it is necessary to reevaluate appropriate canal system in Japan.

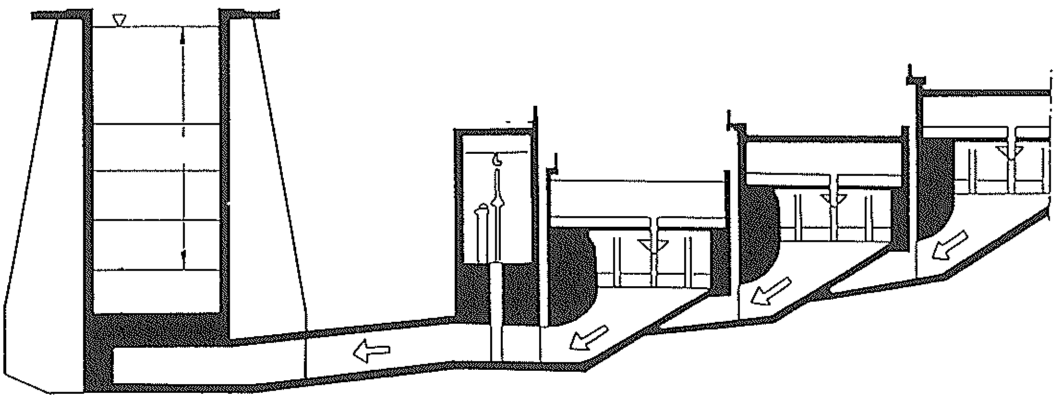


Fig.15 A Concept of Water Saving Lock System by side Pond
(Reference 64)

B) As for trans-isthmian canals, no type of canal had been able to be realized until the beginning of the 19th Century due to lack of basic engineering.
Since an engineering system was to build the Orlean and Langue doc canals in the end of 17th Century existed, a typical low waterhead lock canal could be realized at that time, provided that a sufficient labour force of 7~8,000 people could be obtained.
However, as mentioned before, a technology which could overcome the steep topographic conditions through the Central American Isthmus had not yet been established, and measurment skill was still low, hence, even a small canal in the Isthmus had been impossible in the Spanish era .

C) By the middle of the 19th century,multi-stairs system with small masory lock canal could have been realized in the Isthmus .
A system able to overcome a large waterhead through chaining many traditional masory locks was established by the middle of the 19th century, and technologies for excavating, dredging had been developed. As a result, a small canal like ditch for steam ship might have been realized.

D) By 1882 when de Lesseps began to carry out his Pamana canal, a lock canal, large waterhead lock canal could have been realized.
Most of all major technologies such as excavating and dredging machines, dynamite and mass-concrete had already emerged. De Lesseps, having excavated 59,7 million m^3 of material, would have converted to a lock canal, a Panama canal might have been completed.

E) The U.S. built the Panama canal by applying the advanced technologies at that time.
In 1914 the lock canal of 80km in length with 12 locks was completed. From the chronological development of portland cement, large lock canal like the present Canal was barely able to be realized at that time .

F) Augmentation of vessels and limitation of excavating volume.
As for the canal plans after World War II, due to augmentation of vessels, as shown in Fig.3, a larger canal had been requested. Hence excavating volume in recent other Panama Canal work was 370 million m^3 until 1945. It is far more than that of any major Japanese big project, namely, the Tomei Expressway (66 million m^3), reclamation of Ohgijima (80 million m^3), Port Island in Kobe (80 million m^3) and Shin Kansai International Airport (164 million m^3).
Furthermore, recent sea-level canal plans assumed an excavation volume of over 1,000 million m^3. Regarding the issue of the tremendous volume, the Interoceanic Canal Commission for the sea-level canal plan 1970 stated that the issues not only contains engineering problems, but also political, environmental and financial problems. These problems confronting us today have been caused by these large scales which have been decided based on the largest size of vessel.
Now may be the time to change the basic philosophy of planning.
Hence, it can be said that appropriate lock canal which save excavating cost and water usage should be throughly studied for the second generation Panama canal.
A shaft lock with side pond for 140,000~170,000 DWT vessel may be a recommendable one.

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References

1) Tikuma Shobou: 「History of Engineering-Renaissance」, Vol.6, pp.386~408, 1978~85 (in Japanese)
2) Americana Corporation: 「The Encyclopedia Americana」, Vol.5, 「Canals」, pp.517~523
3) Mc.Garey D.G. : Canal Locks and other Lifting Devices in Inland Navigations, 「The Dock and Harbour Authority」, pp.271~274, pp.302~306, August, 1938
4) Donau H, Schroder D. and Tzschucke H.P. : Des ecluses de faible hauteur aux ouvrages de franchissement des grandes chutes, 「Centenary of the Permanent International Association of Navigation Congresses 1885-1985」, PIANC, pp.173~174, 176, 180, 1985 (in French)
5) Heibonsha: 「World Encyclopedia」, Vol.3, 「Canal」, pp.317~319, 1979 (in Japanese)
6) Nagahiro Y. : On the Onga-Horikawa about the Functional Parts and Restoration, 「Historical Studies in Civil Engineering」, No.11, JSCE, pp.247~258, June, 1992 (in Japanese)
7) Y. Nagao: 「A Story of History of Civil Engineering in Japan」, Kajima Shuppan, pp. 187~192, April 1985 (in Japanese)
8) Endoh G. : 「A Report of the Teizan and Kitakami Canal」, Tohyama Print, May 1989 (in Japanese)
9) Osaka Pref. : 「Chronicle of the Osaka Port」, Vol.1, pp.22~25, Mar. 1959 (in Japanese)
10) Nagano M. : History of Port Development in the World (7) & (8), 「Kouwan」, (7) pp.68 Aug. 1988 & (8) pp.82, Sept. 1988 (in Japanese)
11) Goethals G.E. : 「Introduction, Transaction of the International Congress, Panama Canal I」, S.F. California, Page 2~3, 1915
12) Mack G. : 「The Land Divided-A History of the Panama Canal and other Isthmian Canal Projects」, Octagon Book, New York, pp. 44~45, 49, 1974
13) Nagai A. : 「Tomas Telford and Caledonian Canal」, Nitima, Sept. 1991 (in Japanese)
14) Heibonsha: 「World Encyclopedia」, Vol.3, 「France」, pp.96, 1979 (in Japanese)
15) Americana Corporation: 「The Encyclopedia Americana」, Vol.12, 「Germany」, pp.561
16) Gota Canal Steamship Company: 1992, The Gota Canal
17) Nagano M. : History of Port Development in the World (9) & (13), 「Kouwan」, (9) pp. 80~91, Oct. 1988 & (13) pp. 87~95, Feb. 1989 (in Japanese)
18) Lindsay C.H.F. : 「Panama The Isthmus and Canal」, Philadelphia, The John C. Winston Co., July 1906
19) Edogawa Construction Bureau, Ministry of Construction: 「The Tone Canal」, (in Japanese)
20) Kosizawa A. : Planning History of Amsterdam and Siginficance of the Southern Extension Plan (the Extension Plan "Zuid") by H.P. Berlage Approved in 1917, 「Historical Studies in Civil Engineering」, No. 11, JSCE, pp.155~166, 1991 (in Japanese)
21) Nagano M. : Trend of Philosophy of Port Planning upon History, 「Historical Studies in Civil Engineering」, No.11, JSCE, pp.253~263, June 1992 (in Japanese)
22) General Secretariat of PIANC: 「Ship Lifts」, Report of a Study Commission, PIANC Supplement to Bulletin No.65, 1989
23) Benett I.E. : 「History of the Panama Canal-Its Construction and Builders」, Historical Publishing Company Washington D.C., District National Bank Building, pp.97, 1915
24) Mack G. : 「The Land Divided-A History of the Panama Canal and other Isthmian Canal Projects」, Octagon Book, New York, pp.113~118, 1974
25) Bishop J.B. : 「The Panama Gateway」, Charles Scribner's Sons, N.Y. pp.90, 1913
26) Sullivan J.T. : 「Report Historical and Technical Information relating to the Problem of International Communication by way of the American Isthmus」, Washington Government Printing Office, pp.120~122, 1883

27) Americana Corporation: 「The Encyclopedia Americana」, Vol.8, 「Dams」, pp.438
28) Cowan P.J. : 「The Welland Ship Canal between Lake Ontario and Lake Erie」, Engineering News Record, the first figure behind the cover & PP.1～4, 1913～32
29) Mack G. : 「The Land Divided-A History of the Panama Canal and other Isthmian Canal Projects」, OCTAGON BOOK, New York, pp.127～130, 1974
30) Sullivan J.T. : 「Report Historical and Technical Information relating to the Problem of International Communication by way of the American Isthmus」, Washington Government Printing Office, pp.65～76, 1883
31) Ammen D. : 「Inter-Oceanic Ship Canal Question」, 1880
32) Sullivan J.T. : 「Report Historical and Technical Information relating to the Problem of International Communication by way of the American Isthmus」, Washington Governmeent Printing Office, pp.118～133, 1883
33) Selfridge T.H. : 「Report of Explorations and Surveys to Ascertain the practicability of a Ship Canal between the Atlantic and Pacific Oceans by the way of the Isthmus of Darien」, Washington Government Printing Office, 1874
34) Nagano M: History of Port Development in the World (10), 「Kouwan」, pp.76～83, Jan. 1989 (in Japanese)
35) M. Kinouti & T. Kusaka: 「Story of the Suez Canal」, Vol.47, JSCE, April 1972 (in Japanese)
36) Walker J.G. and other commissioners: 「Report of the Isthmian Canal Commission 1899-1901」, Government Printing Office, pp.44～48, 1904
37) Hodges H.F.: General Design of the Locks, Dams, and Regulating Works of the Panama Canal, 「Transactions of the International Engineering Congress, the Panama Canal II」, S.F. California, pp.1～5, 1915
38) Nagai A. : 「An Autobiography Life of Thomas Telford」, Nitima, Dec. 1985 (in Japanese)
39) Mack G. : 「The Land Divided-A History of the Panama Canal and other Isthmian Canal Projects」, OCTAGON BOOK, New York, pp.330～333, 1974
40) Mack G. : 「The Land Divided-A History of the Panama Canal and other Isthmian Canal Projects」, OCTAGON BOOK, New York, pp.151, 1974
41) Sullivan J.T. : 「Reprt Historical and Technical Information relating to the Problem of International Communication by way of the American Isthmus」, Washington Government Printing Office, pp.65～76
42) Ammen D. : 「Inter-Oceanic Ship Canal Across the American Isthmus」, 「Bulletin of the American Geogrphical Society」, No.11 West 29th Street, 1880
43) McCullough D. : 「The Path between the Seas」, A Touchs Book, Simon and Schuster, N.Y., pp.70～100, 1977
44) Mack G. : 「The Land Divided-A History of the Panama Canal and other Isthmian Canal Projects」, OCTAGON BOOK, New York, pp.287～297, 1974
45) Stratton J.H. : The Future and the Panama Canal, 「Panama Canal The Sea-Level Canal Project」, A Symposium, Proceedings of ASCE., pp.452, 1948
46) Sullivan J.T. : 「Report Historical and Technical Information relating to the Problem of International Communications by way of the American Isthmus」, Washington Government Printing Office, pp.119～120, 132, 1883
47) Yamaguchi K : 「Panama Canal」, Chukou Shinnsho (in Japanese)
48) Walker J.G. and other commissioners: 「Report of the Isthmian Canal Commission 1899-1901」, Government Printing Office, Appendix, 1904
49) Binger W.V., Thompson T.F. : Excavation Slopes, 「Panama Canal-the Sea-Level Canal Project」, A Symposium, Proceedings of ASCE, Vol.74, pp.572, 1948
50) JICA: 「A Study relating alternatives Study on the Panama Canal」, 1987 (in Japanese)
51) Nagano M.: History of Port Development in the World (12), 「Kouwan」, pp.89～92, Dec. 1988 (in Japanese)
52) Cornish H.F. : General Design of the Locks, Dams and regulating Works of the Panama Canal, 「Transactions

of the International Engineering Congress, the Panama Canal II」, S.F., California, pp.66, 1915

53) Nagano M.: History of Port Development in the World (6) & (10), 「Kouwan」, (6) pp. 76~83, Sep. 1988, (10) pp. 78~85, Nov. 1988 (in Japanese)

54) Hodges H.F. : General Design of the Locks, Dams, and Regulating Works of the Panama Canal, 「Transactions of the International Engineering Congress, the Panam a Canal II」, S.F. California, pp. 8~14, 1915

55) Bishop B.J. : 「The Panama Gateway」, Charles Scribner's Sons, N.Y., pp.102, 1913

56) Goethals G.W. : Dry Excavation of the Panama Canal, 「Transactions of the International Engineering Congress, the Panama Canal I」, S.F. California, pp.350~354 1915

57) 79th U.S. Congress: 「Report of the Governor of the Panama Canal」, Under Public Law 280 Jackson Place N.W., Washington D.C. 20506, Dec. 1970

58) Anderson R.B. and other Commissioners: 「Interoceanic Canal Studies 1970」, 726 Jackson Palace N.W., Washington D.C. 20506, Dec. 1970

59) Edgerton G.E. : 「The Third Lock Project」, Jan. 1941

60) ICC: 「The Third Set of Locks」, Panama Canal Twenty-fifth Anversary Book, Aug. 1941

61) KPTM Working Group Report: 「A Working Plan for The Second Panama Canal Project (Draft)」, May 1983

62) Lopez, Moreno Y Asociados S.A. : 「Canal Interoceanico La Alternatives」 (in Spanish)

63) D. Vergara S. : 「El CANAL A NIEVEL」 (in Spanish)

64) General Secretariat of PIANC: 「Final Report of the International Commission for the Study of Locks」, PIANC Supplement Bulletin No.55