ISSN 1346-7328
国総研資料　第８３３号
平　成　27　年３月

国土技術政策総合研究所資料

TECHNICAL NOTE of
National Institute for Land and Infrastructure Management

No.833　　March 2015

Effects on Port Facility Design Regarding the Differences of Natural Disaster Conditions between Japan and Cambodia

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日本とカンボジアの自然災害条件の差異が港湾施設の設計に与える影響

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Technical Note of NILIM
No. 833 March 2015
(YSK-N-304)

Effects on Port Facility Design Regarding the Differences of Natural Disaster Conditions between Japan and Cambodia

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Synopsis

Cambodia has no official port design standards. So, major port development projects have been carried out using design standards from donor countries, e.g., France, Japan, China, etc. This may lead to uneconomical and technically inappropriate designs because those standards may not suit Cambodian conditions. This research aims to develop official port design standards for Cambodia by modifying and harmonizing the Technical Standards and Commentaries for Port and Harbour Facilities in Japan (hereinafter, referred to as Japanese Technical Standards). In this report, ①differences of natural disaster conditions: earthquake, typhoon, and flood, between Japan and Cambodia were evaluated for the estimation of conditions of port facility design. Then, ②suitable structural types of port facilities were evaluated by applying Japanese Technical Standards with regard to the estimated conditions. The evaluation criteria are stability against natural disaster conditions, construction cost, and constructability of each structural type.

As a result ①, (1) Earthquake: horizontal seismic coefficient, kh $\leq$ 0.05, which is much smaller than that in Japan where kh = 0.05-0.27. (2) Typhoon: maximum wind speed, U = 25.7 m/s (i.e., tropical storm); and significant wave height, $H_{1/3}$ = 3.9 m. This value of significant wave height is smaller than that in Japan. (3) Flood: maximum water level, W_m=11.65 m which is about 9.0 m of annual fluctuation. The value of flood range is larger than that in Japan.

②Suitable structural types were evaluated among concrete block (CB), concrete caisson (CC), steel pipe pile (SPP), and steel sheet pile (SSP). CC and SPP are “suitable” and SSP is “not suitable” for both seaports and river ports. CB is “suitable” for seaports, but “not suitable” for river ports because of large seasonal fluctuation of water levels.

Under the limitations and assumptions in this study, our suggestions for port facility design in Cambodia are: (i) effects of earthquake and typhoon should not be considered; (ii) effects of flood should be considered only for river ports. Japanese Technical Standards should be modified with reference to the above conditions of natural disasters, particularly, small kh in Cambodia.

Key Words: development of technical standards, Cambodia, port facility design, natural disaster conditions, statistical analysis of extreme values, construction cost, constructability

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国土技術政策総合研究所資料
No. 833　　　2015 年 3 月
(YSK-N-304)

日本とカンボジアの自然災害条件の差異が港湾施設の設計に与える影響

ヘム　ラムラヴ*・淺井　正**

要　旨

カンボジア国は，独自の港湾施設の設計基準を持たないため，主要な港湾開発プロジェクトではフランス，日本，中国等の援助国の技術基準を用いて進められている．これらの基準はカンボジア国に適合しない部分があるため，非経済的な設計や技術的に不適当な設計を誘引する可能性がある．

このため，本研究ではカンボジア国に適合した設計基準を検討することを目的として，①日本とカンボジア国の自然災害条件の差異を比較することにより，適当な港湾施設の設計条件について検討した．そして，②これらの設計条件を日本の設計基準に適用して比較設計を行うことにより，カンボジア国に最も適当な構造形式について考察した．ここで，比較検討にあたり，その評価基準は，自然災害条件，建設コストおよび施工性の 3 点とした．

結果として，①については，次の 3 種類の主要な自然災害条件の差異が港湾施設の設計に与える影響を評価した．(1)地震の影響：震度法を適用した場合の水平震度 k_h は 0.05 以下であり，日本の場合(k_h=0.05-0.27)と比べて非常に小さい．(2)台風の影響：50 年確率台風時の最大風速 U は 25.7m/s（海上強風警報から海上暴風警報の中間に相当する値）であり，この時のシアヌークビル港沖の有義波高 $H_{1/3}$ は 3.9m である．(3)洪水の影響：メコン河にあるプノンペン港近辺における 50 年確率洪水時の最大水位は 11.65m であり，渇水時との水位差は 9.0m である．

②については，コンクリートブロック(CB)，コンクリートケーソン(CC)，鋼管杭式桟橋(SPP)および鋼板矢板式護岸(SSP)の 4 種類の構造形式について比較設計を行い，カンボジア国に最も適当な構造形式を評価した．海港，河川港ともに CC と SPP は適当と評価され，SSP は不適当と評価された．CB は海港では適当と評価されたが，河川港では不適当と評価された．

今回の検討の限られた条件の下ではあるが，カンボジア国の港湾施設設計では，①地震や台風による影響はあまり考慮しなくてもよいこと，②河川港では洪水の影響を考慮すべきことが示された．技術基準の適用にあたっては，このような自然災害条件，とくに水平震度が非常に小さいことに考慮しながら，カンボジア国の条件に適合させることが重要である．

キーワード：技術基準の開発，カンボジア，港湾施設の設計，自然災害条件，極値統計解析，建設コスト，施工性

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Contents

1 Introduction

1.1 Preface

During the last two decades after the end of prolonged civil war, Cambodia has been struggling for rehabilitation and redevelopment of the transport infrastructures to further promote economic development of the country. Most of the development projects have been supporting by the developed countries, e.g., France, Japan, China, etc. though Official Development Assistance (ODA). Since there is no design standards in Cambodia, most of the design and construction works of the projects are carried out by the contractors coming from those donor countries by applying their own design standards. Those design standards may not be suitable for Cambodian conditions such as natural conditions, materials, skilled labor, equipment, and construction methods. Consequently, Cambodia faces many difficulties in adopting various foreign standards to the country which lead to the uneconomical and technically inappropriate designs.

According to the above situations, Japan have played an important role as the major supporting country in several port development projects in Cambodia as well as other Asian countries. The final goal of this research is to develop official design standards for Cambodia by modifying and harmonizing the Technical Standards and Commentaries for Port and Harbour Facilities in Japan (hereinafter, referred to as Japanese Technical Standards) to be suitable with Cambodian conditions.

In order to achieve the above goal, at this stage, this report aims at evaluating some differences of major natural disasters conditions, i.e., earthquake, typhoon, and flood between Japan and Cambodia which strongly influence the design of port facilities. Secondly, the effects from those differences of natural disaster conditions of both countries were evaluated and the suitable design conditions were recommended for the design of port facilities in Cambodia. Finally, by applying the above design conditions, suitable structural types of port facilities in Cambodian were evaluated to compare with that in Japan based on three criteria such as applicability against natural disasters, construction cost, and constructability of each structural type of quaywall for both seaport and seaport and compare with that of Japan.

As a result, the design conditions for port facilities in Cambodia were recommended considering its natural disasters such as earthquake, typhoon, and flood. And suitable structural types of quaywalls, regarded as the main ports' facilities for both seaports and river ports in Cambodia, were suggested among four structure types such as concrete block, concrete caisson, steel pipe pile, and steel sheet pile.

This approach is important for the harmonization and modification of Japanese Technical Standards to be suitable with Cambodian conditions. For the future research, this approach will be applied to other conditions, e.g., construction materials, skilled-labor/engineer, construction equipment, etc. in order to establish official design standards for port facilities that are suitable to the conditions of Cambodia.

1.2 Basic information of Cambodia

The basic information described in the following sections will necessarily contribute to the understanding of the conditions mainly related to port development demand in Cambodia. These information were categorized into three sections such as geography and climate, economic situations, and current situations of waterborne transport in Cambodia.

1.2.1 Geography and climate

Cambodia, officially known as the Kingdom of Cambodia, is located in the southwestern part of Indochina peninsula in Southeast Asia. It has coastline of 440 km and shared-borders of 2,615 km with Vietnam, Laos, and Thailand (see **Figure 1-1**). And it has the total land area of 181,035 km^2 (about a half of that of Japan). According to the population census 2008 (NIS, 2009), total population was 13.4 million with annual growth rate of 1.54 % in which children (0-14) 33.7%, economically productive age group (15-64) 62%, and the elderly population (over 65) 4.3%. Phnom Penh is the capital city which is the main city in Cambodia. It locates in the south-central region of the country, at the confluence of the Tonle Sap, Mekong, and Bassac rivers. Recently Phnom Penh was expanded about two times of its administrative area to be 678.46 km^2 (0.37% of country's total area) and covers about 10% of total population (Phnom Penh government's homepage).

About two third of the country's territory consists chiefly of plains of the Tonle Sap Basin and the Mekong Lowlands with elevations generally from less than 50 meters above the sea level. Tonle Sap great lake expands and shrinks dramatically ranging from approximately of 16,000 km^2 in rainy season and 2,700 km^2 in dry season (McCartney, M., et al., 2010). Mekong River is the 12th world longest river which flows across Cambodia from north to south with length of 480 km and outflow at the South China Sea in Vietnam territory. About 86 percent of Cambodia's territory (156,000 km^2) is included in the Mekong river basin, the remaining 14 percent draining directly towards the Gulf of Thailand (AQUASTAT, 2011)

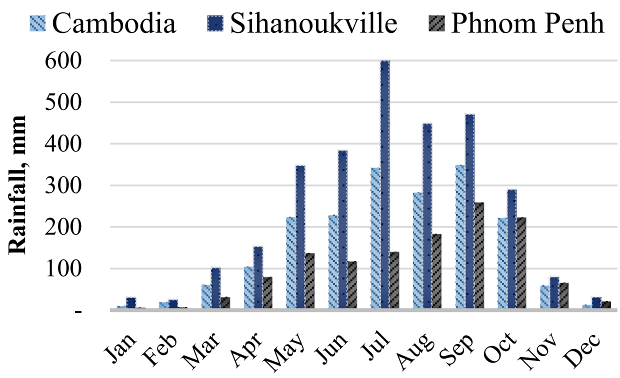
The bottlenecks problems are no longer exist in the major road transport network, however, still there are traffic congestions because roads are small and the volume of traffic is increasing. Currently, many of major road widening projects are ongoing with the assistance from developed countries and international financing

Source: United Nations, 2004

Figure 1-1 Map of Cambodia

organizations. The roads are widened from two to 4 lanes and railroad are improved and rebuild the missing lines. For inland waterway, some bottlenecks are always obstacles due to the shallow water level in dry season and these need to be maintained regularly.

Cambodia is influenced by the monsoon climate which causes it to have two main season, namely rainy season (Northeastern monsoon) takes place from May to October and dry season (Southwestern monsoon) takes place from November to April. The following meteorological data were extracted for representing the condition of the whole area in Cambodia, Sihanoukville, and Phnom Penh based on the original data distributed by the Department of Meteorology, Ministry of Water Resources and Meteorology (MOWRAM), Cambodia from 2003 to 2009 (NIS, 2011). From our calculation result, the annual rainfall in rainy season is 1,651 mm/years and that in dry season is 270 mm/year, which approximately accounted for 86% and 14%, respectively. And, the average rainy day is approximately 130 days, in which rainy season accounted for 105 days (80%). In Phnom Penh (data of Pochentong station), the average annual rainfall in rainy season and dry season is 1,062 mm/year and 215 mm/year, respectively. In Sihanoukville (coastal area), the annual



Data source: Dept. of Meteorology, MOWRAM (provided in NIS, 2011)

Figure 1-2 Rainfall data 2003-2009

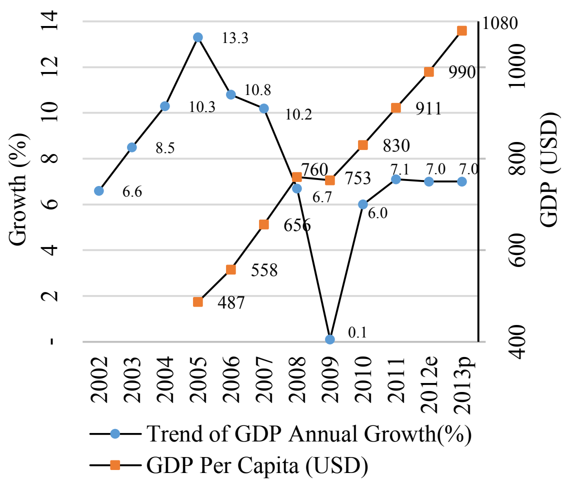
average rainfall in rainy season and dry season is 2,573 mm/year and 434 mm/year, respectively. As shown in **Figure 1-2**, the annual rainfall of throughout Cambodia and two major station where Cambodian major seaport (Preah Sihanouk) and major river port (Phnom Penh) are located.

1.2.2 Economic situations

1.2.2.1 Gross Domestic Product (GDP)

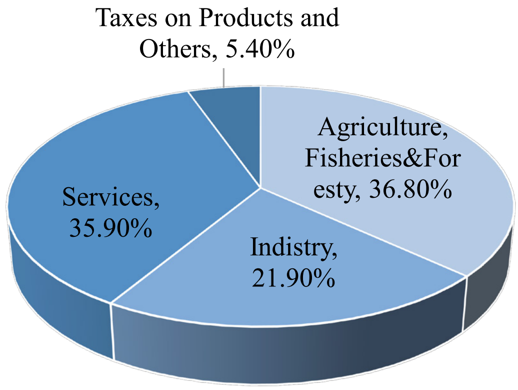
Cambodia has shown sharply economic growth in recent years (see **Figure 1-3**). As described in the report of Cambodian Development Council Report (CDC, 2013), Cambodia's Gross Domestic Product (GDP) maintained a high growth of more than 6.0% per annum from 2002 to 2013, except a drop in 2009. GDP growth rate was increased up to more than 10% for four consecutive years between 2004 and 2007, with a peak high of 13.3% in 2005. Although the growth rate dropped to 0.1% in 2009 following the world economic recession, it recovered to 6.0% in 2010 and 7.1% in 2011 mainly through its renewed exports and tourism sector. According to the Ministry of Economic and Finance (MEF)'s forecast, the growth rates are estimated to be approximately 7.0% in 2012 and 2013. Accordingly, the GDP per capita has also sharply increased to USD 911 (91,100 JPY) which was approximately 87.1% up from USD 487 (48,700 JPY) in 2005. It is projected to reach USD 1,080 (108,000 JPY) in 2013 which enable Cambodia to become a country with lower-middle-class income. Although, GDP is low at present, but it is increasing with relatively high growth rate of about 7 % annually.

As shown the **Figure 1-4**, Cambodia's GDP in 2012 was contributed by the four economic activities of 36.8% from agriculture fisheries & Forestry (major crops: rice, rubber, maize, cassava, etc), 35.9% from services (heavily depending on trade and transportation & communication), 21.9% from industry (major products of manufacturing sector: apparel products, which are directed to exports), and 5.4% from taxes on products and others. According to the study conducted by World Bank about "Cambodia's labor market and employment" in 2008 (EIC, 2008), the share of employment of Cambodian people by economic sector in 2007 are shown as follow: in agriculture sector accounts for 58.1 %, industrial sector accounted for 14.7%, and service sector accounted for 27.5%.



Data source: Ministry of Economic and Finance (MEF), Cambodia; [e: estimated, p: projected]

Figure 1-3 Trends of GDP growth (%) and GDP per capita (USD)



Data source: Ministry of Economic and Finance (MEF), Cambodia

Figure 1-4 GDP by economic activity 2012

1.2.2.2 Investment

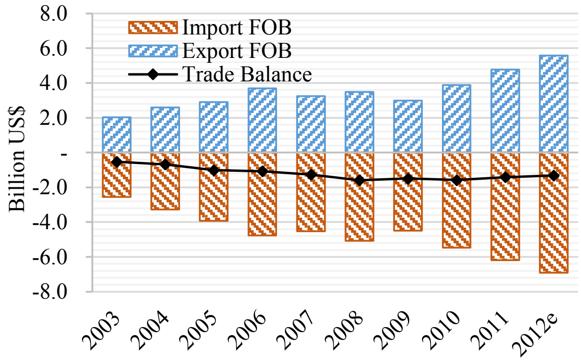
In Cambodia, all investors can invest in all economic sectors including industrial sector, service sector as well as natural resources sector, except land ownership which is reserved to natural and legal Cambodia citizens (Jorge, M., 2012). Cambodian has seen to be attractive to investors in some reasons: low wages, liberal government, access to not Cambodian market but also a market of ASEAN countries with total population of about 600 million. Moreover, through the goal of regional economic integration by 2015 by ASEAN Economic Community (AEC), the ASEAN will be transformed into a region with free ASEAN economic integration which enable the free movement of goods, services, investment, skilled labour, and freer flow of capital (AEC's homepage). This would be an advantageous for Cambodia to attract more investors. Also, as one of the poorest country of WTO member, Cambodia is strongly supported in the form of international force to negotiate and access to the world market which bring Foreign Direct Investment (FDI) to increase production capacity (Jorge, M., 2012).

According to the data distributed by CDC, the accumulated amount from FDIs by the country approved between 1994-2012 (Sep.) is 42.346 billion USD (4234.6 billion JPY) in which the largest amount of 9.1 billion USD (910 billion JPY) came from China (hereinafter, assumed conversion rate: 1USD=100 JPY). The second biggest FDI provided is Korea following by Malaysia, while Japan stands at the 14th rank with a accumulated amount of 157 million USD (15.7 billion JPY).

From December 2005, since the issuance of the law on the establishment and management of the Special Economic Zones (SEZs), to December 2012, 138 qualified investment projects (QIPs) have been approved located in the SEZs and the approved investment has amounted to 1.6 billion USD (160 billion JPY). The locations of SEZs are mostly concentrated along coastal area (close to major seaport) and Svay Rieng Province (Cambodia-Vietnam borders). The investment projects in SEZs are mainly the manufacturing industries. Therefore, seaports are the major logistics for supporting those manufacturing industries for their materials or parts supplies as well as the distribution of their products to the world markets.

1.2.2.3 Trade

As shown in **Figure 1-5**, the trade performance of Cambodia had shown the increasing trend until 2008. While the trade volume dropped in 2009 due to the global financial crisis, it has been recovering since 2010.

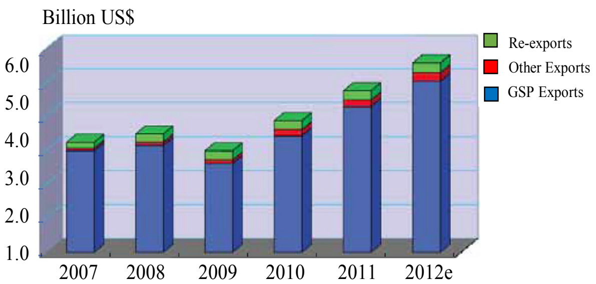


Source: Ministry of Economic and Finance (MEF), Cambodia; ["e" estimated, "FOB" Free On Board]

Figure 1-5 Trade balance 2003 – 2012

Cambodia continuously records a trade deficit. After the gap suddenly widened in 2005, it has been relatively stable at around USD 1.4 – 1.5 billion (140-150 billion JPY) increased by 17% from 2011, while the import amount is estimated to increase by 12% in 2012 reaching USD 6.9 billion (690 billion JPY).

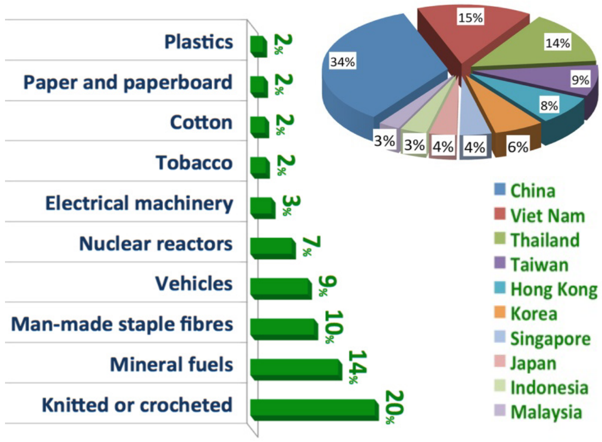
Cambodia's exports have continuously shown a steady growth up to the present, except 2009. According to the MEF's statistics, exports reached approximately 4.8 billion USD (480 billion JPY) in 2011 (**Figure 1-6**). As seen in the **Figure 1-6**, The Garment Sector Product (GSP) export component, the main product, the garments, for two major exporting markets US and EU, occupies the large share among three components and accounts for approximately two/third of total exports. Although GSP exports decreased in 2009, it has been back to the growth trend in 2010 and 2011. Export of other products also shows the similar tendency. On the other hand, re-export products continuously increased from 2006 until 2012.



Source: Ministry of Economic and Finance (MEF), Cambodia

Figure 1-6 Exports 2007 – 2012

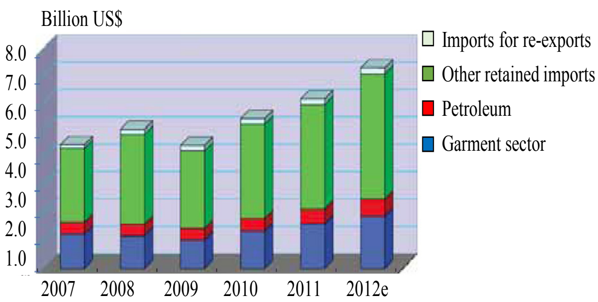
As shown in **Figure 1-7**. Among these ten products knitted or crocheted products which are imported for use in the production in garment sector. Among the 10 countries, China alone accounted for 34% of the total import.



Source: Department of Trade Statistics and Information, Ministry of Commerce (MOC), Cambodia

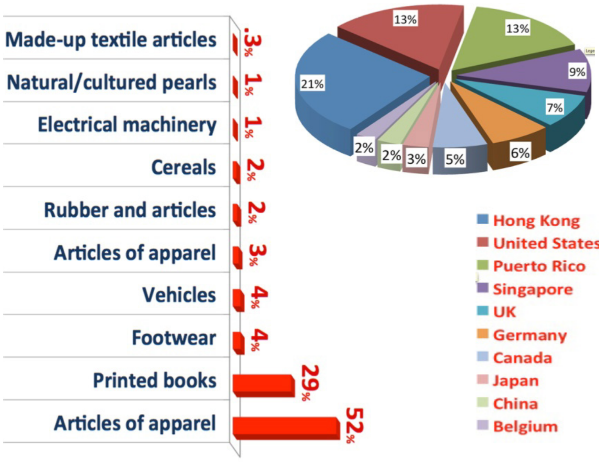
Figure 1-7 Cambodia's top 10 import products and top 10 import countries (2012)

The growth of Cambodian imports has been much higher than growth of exports. As shown in the **Figure 1-8**, although the import dropped in 2009, it recovered in 2010 and has shown continuous growth until 2012. The total amount of import was approximately 6.1 billion (610 billion JPY) in 2011 and it is expected to be 7.3 billion USD (730 billion JPY) in 2012. The garment sector is still expected to be the main importing source in 2012



Source: Ministry of Economic and Finance (MEF), Cambodia

Figure 1-8 Imports 2007 – 2012



Source: Department of Trade Statistics and Information, Ministry of Commerce (MOC), Cambodia

Figure 1-9: Cambodia's top 10 export products and top 10 export countries (2012)

accounting for 26.2% of total imports. As shown in **Figure 1-9**, among the top 10 export products, article of apparel accounted for 52% and the top export country is Hong Kong which accounted for 21% of the total export products.

If the GDP of Cambodia keeps increasing with the growth rate as it has performed so far, in the future, the GDP per capita will be increased so that the export and export products will be diversified from garment products to agriculture and/or industrial products. Therefore, port facilities will be required for the import and export of these kinds of products.

1.3 Transport network

1.3.1 Asian transport network

Cambodia links to the neighboring countries as well as other Asian countries through all modes of transport,

Source: UNESCAP, 2013 (modified using additional information from MPWT, 2012)

Figure 1-10 Integrated map of Asian Highway, Trans-Asian Railway & Dry Ports of international importance particularly, highway, railway, as well as waterborne transport. As shown in **Figure 1-10**, Asian Highway (AH) connects Phnom Penh capital city with Bangkork (Thailand) and Ho Chi Minch (Vietnam) via AH1 at the direction of East –West, and connects Sihanoukville Port to Phnom Penh and Laos. Moreover, other two lines running across coastal area and the northern port of country with Thailand and Vietnam.

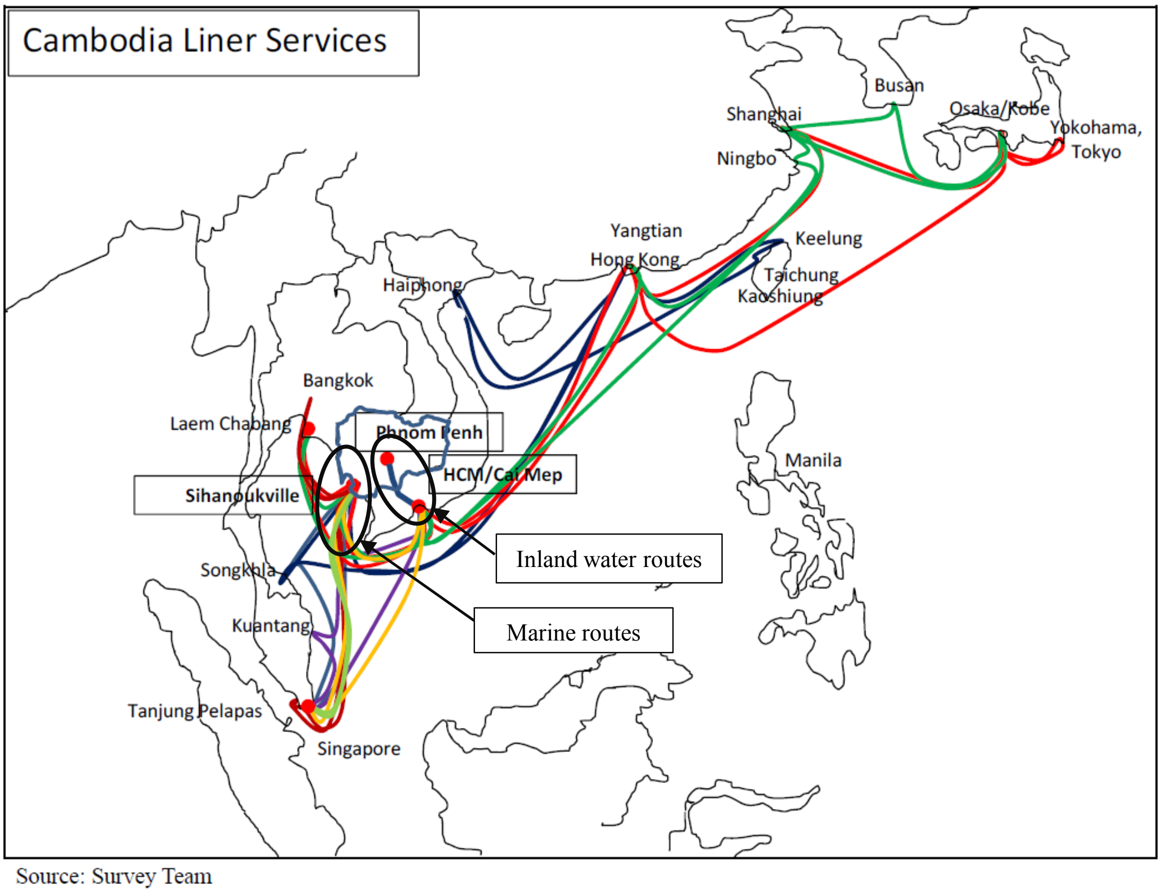
According to MPWT's report (MPWT, 2012), there are two existing railway lines in Cambodia: (1) Northern Line (NL) links Phnom Penh to Poi Pet town at Thai border by running across Battambang, which is one of Cambodia's main rice growing provinces. (2) Southern line (SL) links Phnom Penh to Sihanoukville Port. Some sections of this line are missing and damage due to the civil war, but these sections are currently being rehabilitated under financial support mainly from Asian Development Bank. Based on the **Figure 1-10**, this is a new line is being planned for connecting between Phnom Penh and Ho Chi Minh.

Since Cambodia is located at the heart of ASEAN region, it is advantageous for Cambodia to attract more investors to the country. Cambodia might be not only a good place for production since it has plenty of young labour force with relatively low wage, but also a central market for distribution of products to ASEAN region market. Moreover, as mentioned in section **1.2.2.2. Investment**, the ASEAN Economic Integration will facilitate investors in Cambodia to access parts and other materials for their needs from other ASEAN countries easily.

1.3.2 International maritime transportation around Cambodia

(Please refer to the Appendix for the detail of waterborne transport in Cambodia. In this section, only a brief introduction of Cambodian ports art provide)

According to JICA's preparatory survey report (JICA, 2013), the flowing information of international maritime transport around Cambodia are provide as follows. The international liner services are calling at Sihanoukville Port, but services are limited to ASEAN and East Asian ports as shown in **Figure 1-11**. Directly linked ports are Singapore, Tanjung Pelapas, Hong Kong, Ho Chi Minh, Cai Mep, Laem Chabang, Songkhla, Kuantang, Kobe, Osaka, Tokyo, Yokohama, Shanghai, Busan, Ningbo, and Yangtian. Singapore Port plays the role of a hub port which connects Sihanoukville Port to major trunk services to Europe and North America.



Source: JICA, 2013

Figure 1-11 Liner service loops from Sihanoukville port (as of 2012)

Phnom Penh Port is a river port and container service is limited to Ho Chi Minh and Cai Mep. Vessels deployed are barge type container vessels with a capacity of 120 TEUs or less. All containers are transshipped at HCM or Cai Mep Port and carried to final destinations. Due to the availability of truck liner services from Cai Mep Port, export containers from Phnom Penh Port are destined for North America and East Asian countries. Containers to Europe are mainly carried through Sihanoukville Port.

Shipping companies serving at Phnom Penh Port are Sovereign, GEMADEPT, and New Port Cypress (Ben Line Agencies). Other shipping companies suspended services to Phnom Penh Port as of October 2012. GEMADEPT has the largest share of 66.7% followed by Sovereign of 22.1% and New Port Cypress of 11.3%. Liner shipping loops from/to Sihanoukville port are shown in **Figure 1-11**.

1.3.3 Demand for port development

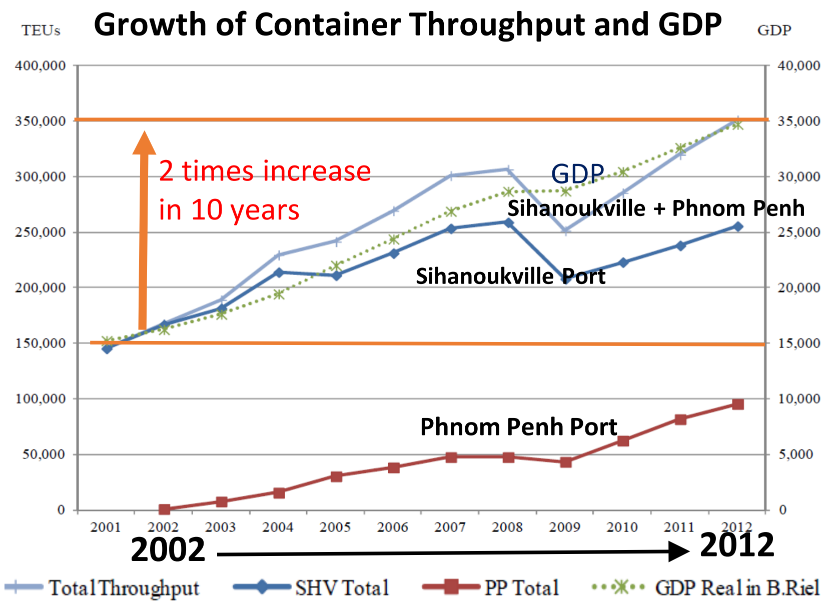
Based on our hearing survey with JICA expert in Cambodia in December, 2014, the import and export containers in Cambodian are transported through three routes. From Phnom Penh to Sihanoukville Port accounted for 50% and Phnom Penh to Ho Chi Minh through inland waterway via Mekong river route accounted for 35% and via national road NR1 accounted for 15%.

According to the data provided in JICA's (JICA, 2013), the trends of container throughput via Sihanoukville Port and Phnom Penh Port are shown with relation to GDP growth (see **Figure 1-12**). The **Figure 1-12** shows container throughput has a close relationship with economic growth, however, container throughput in 2008 and 2009 showed unusual trends due to the world recession.

Considering the period of 11 years from 2001 to 2012, the total container throughput of Sihanoukville Port and Phnom Penh port show the trend with drastically growth of more than double from 150,000 TEUs to 350,000 TEUs. Likewise, the GDP also increased from 15,000 billion Riel (428.57 billion JPY) to 35,000 billion Riel (1,000 billion JPY) (assumed exchange rate used: 100 JPY=3,500 KHR (Riel), rate provided by NBC (National Bank of Cambodia)'s homepage on February, 2015).

Cambodia economic is expected to increasingly grow from year to year. Therefore, the port development is required to support this economic growth. However, as shown in **Figure 1-13**, Cambodian ports are relatively small, especially river ports. For river transport, there are several bottlenecks problems particularly during the dry season (refer to the Appendix for the details of bottlenecks problems along Cambodia waterway routes). **Figure 1-13** shows the conditions of ports in Cambodia. The middle map shows the maximum size of vessels during the mean high water level in rainy season and mean low water level in dry season (Seng, S., 2010) together with some photos of local river ports (Sor, V., 2010) and photos of Phnom Penh Port and Sihanoukville Port are provided by a country reports (JICA Training Program, 2013).

To support the future port development, Cambodia should have its own official port design standards that are suitable to its conditions in order assure the economical and technically appropriate designs of port facilities.



Source: JICA, 2013 (modified)

Figure 1-12 Trends of container throughput and GDP growth

Source: prepared by using photos from Sor (2010), Seng (2010), and JICA Training Program (2013)

Figure 1-13 Cambodia seaport and river ports

2 Research Scheme

As shown in the **Figure 2-1**, there are three main components of research scheme to be discussed as a whole to achieve future goal of development of official design standards for port facilities in Cambodia such as research motivation/problem, research objective, and research methodology. The explanation of each component is described as the followings.

2.1 Research motivation

Cambodia's major ports have been built and expanded under the Official Development Assistance (ODA) provided by developed countries. For instant, Sihanoukville Port was firstly built by France in 1956 – 1969. After political stability in mid-1990s up to present, Japan has been continuously assisting in rehabilitation and expansion of its capacities under its ODA loan. Recently, a modern container terminal of Phnom Penh Port was built under the ODA loan from China. Consequently, port facilities in Cambodia was built using design standards of various countries which may lead to uneconomical and technically inappropriate designs because the conditions of Cambodia are different from that of the above countries. Therefore, Cambodia should have its own official standards for port facilities. Since Japan has been continuously assisting in both major ports development in Cambodia and other ASEAN countries, the aim of this research considered to modify and harmonize Japan Technical Standards for Cambodia.

2.2 Research objective

The final goal of this research aimed to develop official port design standards in Cambodia by modifying and harmonizing the Technical Standards and Commentaries for Port and Harbour Facilities in Japan (hereinafter, referred to as, Japanese Technial Standards) to be suitable to Cambodia's conditions. At this stage, we focused mainly on natural disasters that may affect port structure design.

2.3 Research methodology

To achieve the above final goal, there four steps of research methodology were developed as shown in **Figure 2-1.** And, each step is described as follows.

First step: all the conditions concerning to the establishment of technical standards for port facilities will be compared between Japan and Cambodia. Some of the main conditions were listed in the **Figure 2-1** such as natural disasters, labour/engineer, construction materials, construction equipment, etc. However, in this report, we focused mainly on the natural disaster conditions.

In this report, therefore, the differences of some natural disaster conditions between Japan and Cambodia were evaluated for the estimation of conditions of port facility design in Cambodia. The design conditions of port facilities were estimated from the differences of conditions of three major natural disasters between Japan and Cambodia, namely, earthquake, typhoon, and flood.

Second step: this step is to evaluate how the differences of the conditions between the two countries would affect the design of port facilities in Cambodia. The evaluation were carried out by applying the estimated design conditions to Japanese Technical Standards to the design of quaywall structures for Cambodia seaport and river port. As for other design conditions and parameters are obtained from the real designs of major ports in Cambodia. There are four different structural types considered for the evaluation such as concrete block, concrete caisson, steel pipe pile, and steel sheet pile. And the evaluation criteria for the suitable structural types are applicability against natural disasters, construction cost, and constructability of each structural type.

Third step: by considering the results from the first and second steps, the modification of Japanese Technical Standards for the design of port facilities in Cambodia could be suggested. Some part the Japanese Technical Standards that do not affect the design of Cambodian ports will be kept and some parts that affect the design would be modified.

Fourth step: this step is to apply the harmonized technical standards to the design of port facilities in Cambodia. So, every port development project in Cambodia would respect the official standards. Further modification might be required after the implementation of the standards and receiving the feedbacks from the port construction projects.

In this report, the First Step and Second Step will be discussed in Chapter 3 and Chapter 4, respectively.

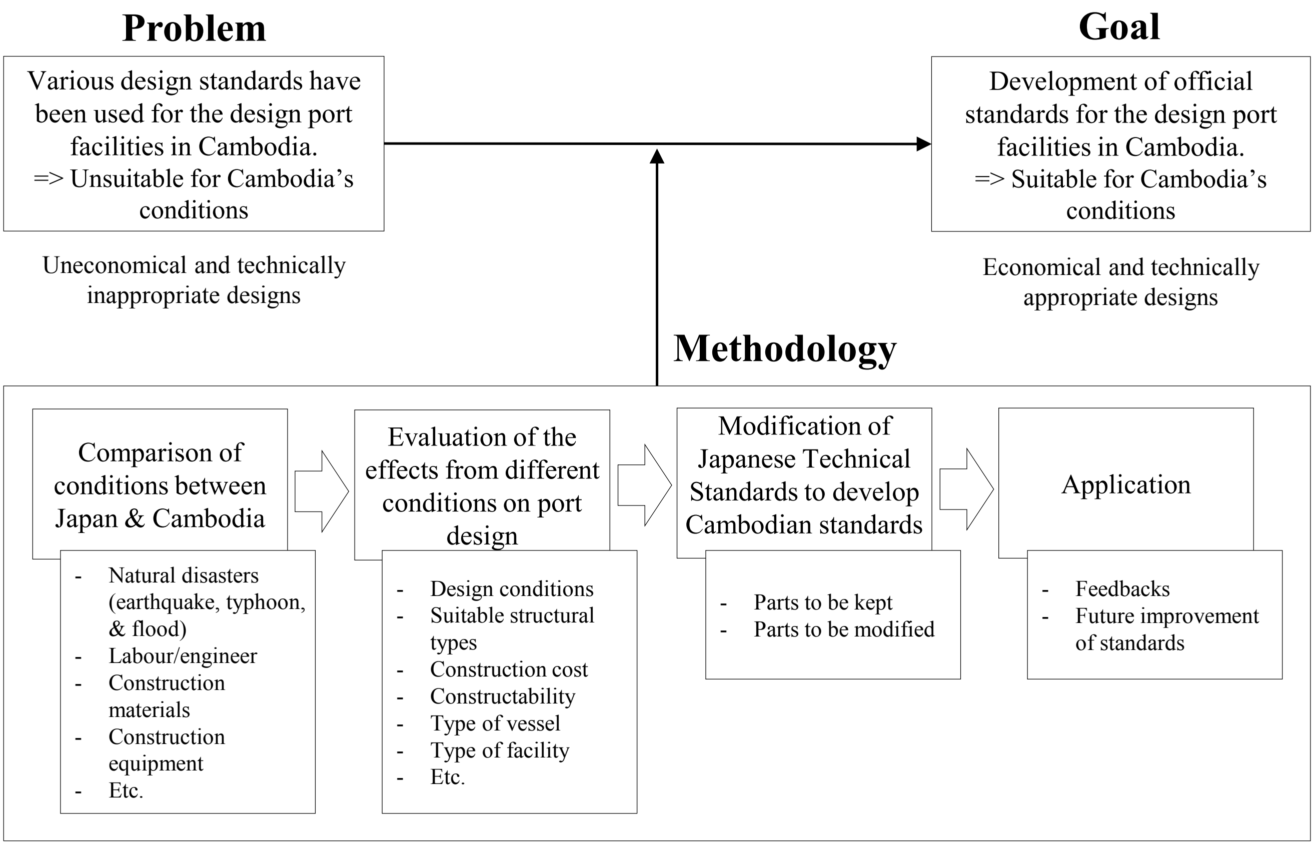


Figure 2-1 Research scheme

3 Comparison of Natural Disaster Conditions between Japan and Cambodia

3.1 Introduction

According to information provided by Cabinet Office, Japan (Cabinet Office, 2011), the number of disasters around the world is increasing, and disasters remain a major drawback to sustainable development. Reducing vulnerabilities to natural hazards and damage caused by them is an inevitable challenge in the international community.

Asia in particular is a region where many disasters occur, as exemplified by the Indian Ocean tsunami disaster in late 2004, killing approximately 230,000 people, and the Sichuan earthquake in 2008 which took the lives of approximately 90,000 people. Looking at disasters worldwide in the most recent three decades (1979-2008), approximately 40% occurred in Asia, accounting for more than 90% of the people killed and affected and as much as 50% of the economic damage.

In Japan there is a great loss of people's lives and property and national property every year due to natural disasters such as earthquake, tsunami, typhoon, volcanic eruption, and flood. For example, based on disaster database (EM-DAT, 2014), 161,794 people were killed by 44 earthquakes and 32,576 people were killed by 14 tsunamis. Therefore, most of the important infrastructures must be built with the strength against disasters. Particularly, ports and harbors in Japan are important to its economy because they are the mainstays of 99% of foreign trade and 44% of domestic distribution (Shinanogawa River Office, MLIT). Therefore, the effects from natural disasters such as earthquake, tsunami, and typhoon were strictly considered in Japanese Technical Standards.

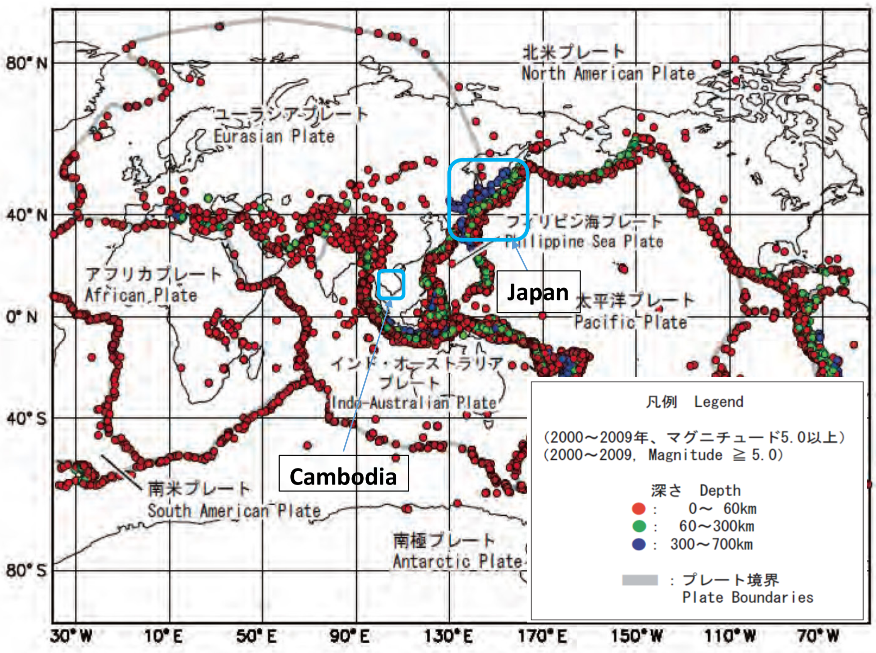
On the other hand, in Cambodia, flood is the major disaster which frequently occur and destroy people's lives and property in a wide area of the country. Cambodia also affected by typhoon but the scale of typhoon is in the category of tropical storm and tropical depression. For the earthquake, Cambodia has no record of these disasters. Therefore, natural disaster might have less effects on port facilities.

According to the above information, there are greatly differences of natural disaster conditions between Japan and Cambodia. For example, as shown in **Figure 3-1**, there is no earthquake occurred in Cambodia while many earthquakes occurred in Japan. Therefore, in order to harmonize Japan technical standards for port facilities design in Cambodia, the study of the differences between natural disaster conditions between the two countries is dispensable. The intensity of effects from natural disaster cause port structures to have a greater strength which require advanced construction techniques and equipment. Consequently, this would result higher cost of construction. For that reason, this study considered the major three disaster that might influence port facilities: earthquake, typhoon, and flood as follows.

3.2 Earthquake

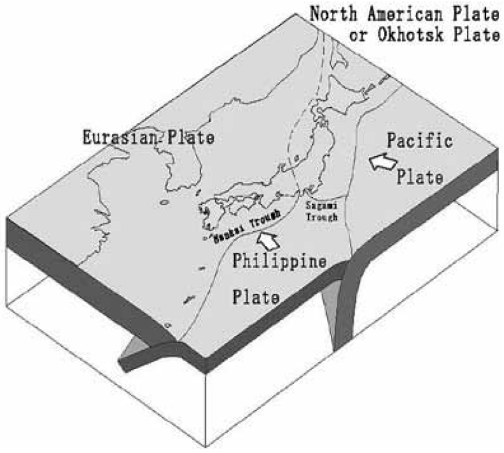
3.2.1 Earthquake in Japan

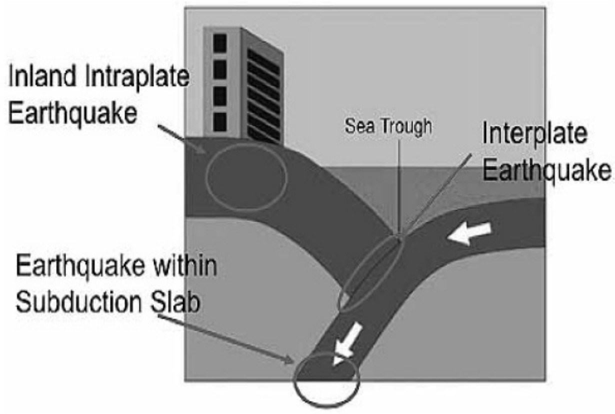
Earthquake is one of the worst natural disasters recognized as a major threat to human's lives and



Source: Cabinet Office, Japan, 2011

Figure 3-1 Earthquake locations and location of Cambodia and Japan





Source: City of Kobe, 2010

Figure 3-2 Tectonic plate (left) and typical earthquake locations in colliding plate (right)

properties. Japan is located in the Circum-Pacific Mobile Belt or sometime called "Ring of Fire" where many volcanoes are active and very strong earthquakes are frequently encountered due to the movement of plates so called plate tectonics (Cabinet Office, 2011). Although the country cover only 0.25% of the land area on the planet, the number of earthquakes is quite high. For instant, there were 212 earthquakes over the world total number of earthquakes of 1036 with magnitude M6.0 or higher were recorded from 2000 to 2009.

According to the report from the City of Kobe (City of Kobe, 2010), near the islands of Japan, there is a slow but steady northwestward movement of the Pacific Plate against the Eurasian Plate and westward movement against North American Plate. As shown in **Figure 3-2**, the Pacific Plate and the Philippine Plate are subducting under the Eurasian Plate and the North America Plate or the Okhotsk Plate. Such plate movements generate forces in the plates or slabs that eventually lead to failure or fault rupture at the interface of the colliding plate slabs or within those slabs. These fault ruptures are the sources of earthquakes, which can be divided into 3 types depending on the location of the fault rupture: the inland intraplate earthquake, the interplate earthquake, and the earthquake occurring within the subduction slab. Interplate earthquakes usually result in a long duration of shaking that reaches the inland area with some time delay following fault rupture. This type of earthquake also often results in a tsunami when the rupture occurs deep in the sea. Earthquakes occurring with the subduction slab result in shaking and damage that is more widely spread over the inland as the location of the rupture is very deep, sometimes as deep as 100 km, within the earth's crust.

3.2.2 Design conditions for port facilities against earthquake in Japan

According to Ministry of Transport, Japan (1999), in the design of port and harbor facilities, the effect of earthquakes shall be carefully examined so that the facilities retain appropriate seismic resistance. The earthquake resistance of port and harbour facilities are classified into two categories and their specifications are listed in the **Table 3-1**:

(1) Port and harbor facilities shall be capable of retaining their required structural stability without losing their function when subjected to the "Level 1" earthquake motion (earthquake motion with a high probability of occurrence during the lifetime of facilities).

Table 3-1 Earthquake motion and earthquake resistance of port and harbor facilities to be considered for design

Source: Ministry of Transport, Japan (1999)

Ground motion level	Ground motion considered for seismic design	Applicable facilities	Earthquake resistance
Level 1	Ground motion with a 75-year return period	All facilities (except facilities that are regulated according to other standards)	Do not lose their function
Level 2	Ground motion from intra-plate earthquake or ground motion from inter-plate earthquake. The return period is anticipated to be several hundred years or more	High seismic resistant structures (high seismic resistant quaywalls, high seismic resistant revetments for refuge and rescue centers, etc.). In addition, port and harbor facilities such as bridges and immersed tunnels that must take the Level 2 earthquake motion into consideration in design.	Retain their expected function

(2) High seismic resistant structures (particularly important facilities whose seismic resistance is to be reinforced) shall be the structures that will sustain only slight damage during the "Level 2" earthquake motion (earthquake motion that has a very low probability of occurrence during the lifetime of facilities, but which is very large when it occurs) and whose functions can be quickly restored after a Level 2 earthquake and are able to retain their expected function throughout the rest of its lifetime.

In the Japanese Technical Standards (Ministry of Transport, Japan (1999), the horizontal seismic coefficient (kh) for design is given as a product of the regional seismic coefficient, the soil-type coefficient and the importance coefficient. For simplicity, the vertical seismic coefficient is neglected. The regional seismic coefficient takes a value between 0.08 and 0.15, depending on the regional seismicity. The soil-type coefficient takes a value between 0.8 and 1.2. The importance coefficient takes a value between 0.8 and 1.5. As a consequent, the horizontal seismic coefficient for design ranges from 0.05 to 0.27.

For structure having a comparatively short natural period and large damping factor, the seismic load shall be determined by the product of kh value and dead load (either including or excluding surcharge that is most damaging to the port and harbor facilities) and shall be applied to center of the gravity of facilities.

For the high seismic resistance structures, the design kh value shall be determined after comprehensive judgment of the result calculated using the above method and the result calculated considering the peak ground acceleration at the surface by equations (Ministry of Transport (1999).

(a) When α is 200 Gal or less

$$k_h = \alpha / g$$

(b) When α is larger than 200 Gal

$$k_h = \frac{1}{3}(\alpha / g)^{1/3}$$

where

k_h : horizontal seismic coefficient
α : peak ground acceleration at the surface (Gal)
g : gravitational acceleration (Gal)

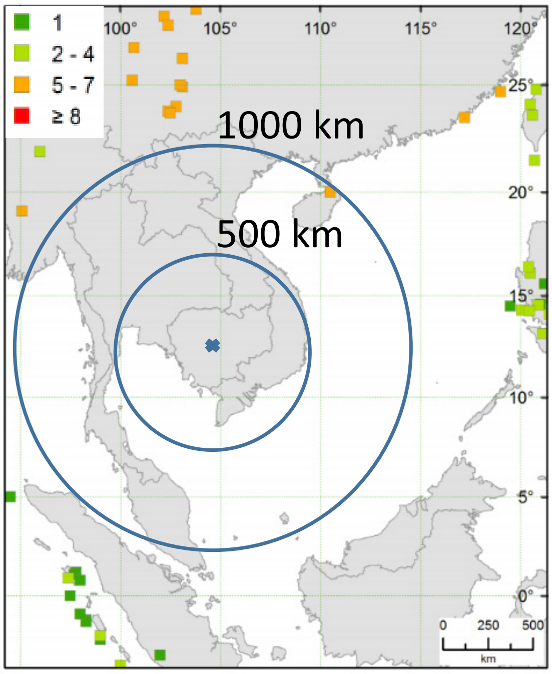
3.2.3 Earthquake in Cambodia

Cambodia has no or very little earthquake seismic activity because it is not located near continental plate boundaries like Japan. Based on disaster database (EM-DAT, 2014), there was no record of damages caused by earthquakes in Cambodia. Likewise, Cambodian also has no effects from tsunami because its coastline faces to the narrow bay of Gulf of Thailand that seems to have been protected by its surrounding islands and neighboring countries such as Thailand (West) and Vietnam (East).

Figure 3-3 shows the locations and the number of records per earthquake in South-East Asia excluding Indonesia and the Philippines in Global Historical Earthquake Archive and Catalogue, 1000-1903 (GHEA) (Albini, P., et al., 2013). It also shows a marked variation in seismicity. While major earthquakes have affected Burmese territory from time to time, much of the region is highly stable. There is some seismicity in the north of Vietnam arising from tectonics associated with the Red River Fault, but this has not given rise to major earthquakes, at least in the 20th century. In Albini, (2013), it was stated that within the region, large earthquakes are only found in north-west Vietnam and north Laos, and that in the rest of Vietnam, southern Laos, and Cambodia, no large earthquakes are known

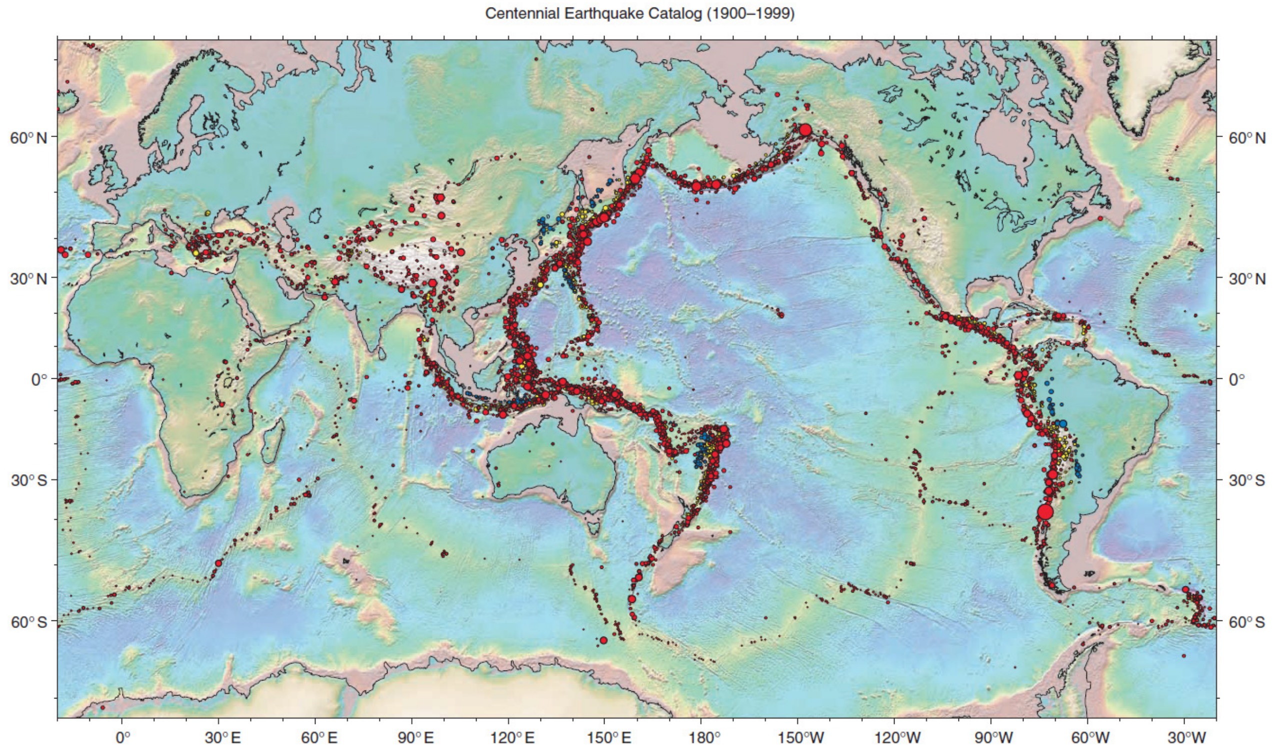
For Cambodia it seems safe to say that no earthquakes have occurred that would merit inclusion in the present study. Based on the **Figure 3-3** below, some locations of earthquakes found at the distance as far as 1000 km from the center of Cambodia which mean that the effect from these earthquake is small and it could be negligible (Albini, P., et al., 2013).

As shown in **Figure 3-4**, the Centennial Earthquake Catalog (1900-1999) was a global locations and magnitudes of instrumentally recorded earthquakes during the 20th century. For recent years (1964-1999) the magnitude cut-off is 5.5, and the catalog is complete at this magnitude threshold. For the historical period (1900-



Source: Albini, P., et al., 2013

Figure 3-3 Earthquakes in GHEA (1000-1903) in South East Asia, and number of records per earthquake



Color Plate 15 Global earthquake locations from 1900 to 1999 taken from the centennial catalog. Bathymetry/topography are from the database of Smith and Sandwell (1997). Earthquakes relocated in this study are shown by filled circles and unrelocated earthquakes by filled hexagons. Symbol fill is color-coded according to focal depth h: red = shallow events ($h < 70$ km); yellow = intermediate ($70 \leq h < 350$ km); and blue = deep ($h \geq 350$ km). A thick symbol outline is used for events with magnitudes greater or equal than 8.0.

Source: http://earthquake.usgs.gov/data/centennial/centennial.pdf

Figure 3-4 Centennial Earthquake Locations 1900-1999

1963) the magnitude cut-off chosen was 6.5 although the resulting catalog is complete only to the magnitude 7.0 (Engdahl and Villaseñor, 2002).

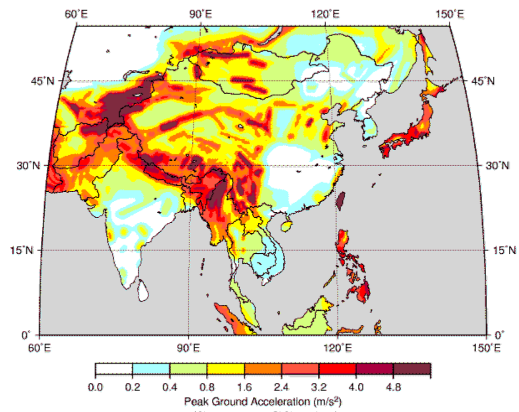
Based on the catalog, there is no record of locations of earthquake shown in the Cambodia territory and its nearby locations.

2.2.4 Design conditions for port facilities against earthquake in Cambodia

The above two catalogues can prove that there is no earthquake occur in Cambodia for a long historical record. From the first catalog, it is concluded that there is major earthquake of with magnitude of 6.5 or higher with return period of about 1000 years (1000-1903) and with magnitude of 5.5 or higher with return period of 100 years (1964-1999). Therefore, it is concluded that Cambodia has no or little effect from earthquake incident.

For this study, we attempt to calculate the design horizontal seismic coefficient for reference of port design condition considering earthquake for Cambodian port by using the equation from Japanese Technical Standards in relation to the peak ground acceleration as stated in the above section.

As shown **Figure 3-5**, the value of peak ground acceleration (PGA) in ASIA provided by Global Seismic Hazard Assessment Program (GSHAP), Cambodia is shown to fall within the peak ground acceleration from 0.2 to 0.4 m/s^2. By applying the maximum value of PGA=0.4 m/s^2 into the above equation, the horizontal seismic coefficient results to 0.041. Therefore, the horizontal seismic coefficient of 0.05 is suggested for design of port facilities in Cambodia. Based on Japanese Technical Standards, the value of kh of 0.05 is equal to the minimum value for port design in Japan where kh = 0.05-0.27.



(Source: GSHAP)

Figure 3-5 Peak ground acceleration

*The seismic hazard map of Asia depicting peak ground acceleration (PGA), given in units of m/s^2, with a 10% chance of exceedance in 50 years. The site classification is rock.

3.3 Typhoon

3.3.1 Introduction

Because of the data of typhoon defined for Japan and Cambodia are acquired from different sources of databases, it is necessary to explain the different characteristics of the data. The typhoon data provided by the JTWC (Joint Typhoon Warning Center) are used for Cambodia, while the typhoon data provided by JMA (Japan Meteorological Agency) are used for Japan. The typhoon data for Japan, the original data from JMA were used directly, but that of Cambodia were defined by the authors for this study.

3.3.2 Classification and scale of typhoon

Based on the information shown in the NII (National Institute of Informatics)' homepage, the classification of typhoon are described as follows. The tropical storms in the world are called by different names in each basin, such as a "typhoon" and a "hurricane," but the standard to be called by such names is the same: more than 64 kt (33 m/s) of wind. In fact, it is a little more complicated between the word "Typhoon" and Hurricane", because not only the location of storm is different but also the intensity.

In Japan, the word "Taifu" or "Taihu" (the Japanese word for "Typhoon") has a slightly different meaning. As shown the **Table 3-2**, the difference of "Taifu" and "Typhoon" is in the intensity, while the difference of "Typhoon" and "Hurricane" is in the location. It is noted that the definition of "typhoon" is different between the Japanese standard and the international standard. A tropical storm with the wind speed of more than 34 kt (or 18 m/s) is called a "typhoon" in Japan, while in the international standard (International Category), that with the wind speed of more than 64 kt (33 m/s) is called a "typhoon."

Table 3-2 Comparison of "Taifu/Taihu", "Typhoon", "Hurricane"

Location	Max. Wind 34-64 knots	Max. Wind 64- knots
Western North Pacific Region	Taifu (Taihu)	
	(Severe) Tropical Storm	Typhoon
North Atlantic Basin	Tropical Storm	Hurricane

The intensity of a tropical storm is classified by the maximum sustained wind (10-min mean) according to World Meteorological Organization (WMO). The following **Table 3-3** summarizes categories for tropical storms. Here "Tropical Depression" is a tropical storm weaker than a typhoon, and a tropical storm stronger than a typhoon, JMA classification has four levels (previously five) and international classification has three levels.

As shown in **Table 3-4**, JTWC and other US meteorological organizations use Saffir-Simpson Scale to classify tropical storms stronger than the hurricane (or typhoon) intensity based on the maximum sustained wind (1-min mean).

Table 3-3 Classification of intensity of typhoon

Intensity Class	Maximum Sustained Wind (10-min Mean)			International Category	Class
	kt (knot)	m/s	km/h		
Low Pressure Area	central position cannot be accurately identified			Low Pressure Area	-
Tropical Depression	-33	-17	-62	Tropical Depression (TD)	2
Typhoon	34 - 47	18 - 24	63 - 88	Tropical Storm (TS)	3
	48 - 63	25 - 32	89 - 118	Severe Tropical Storm (STS)	4
Strong Typhoon	64 - 84	33 - 43	119 - 156	Typhoon (TY) or Hurricane	5
Very Strong Typhoon	85 - 104	44 - 53	157 - 192		
Violent Typhoon	105 -	54 -	193 -		

Table 3-4 Classification of intensity of typhoons and hurricanes (USA Standard)

International Category	Category (Saffir-Simpson Scale)	Maximum Sustained Wind (1-min Mean)		
		knots (kt)	(m/s)	(km/h)
Typhoon / Hurricane	1	64 - 82	33 - 42	119 - 153
Typhoon / Hurricane	2	83 - 95	43 - 48	154 - 177
Typhoon / Hurricane	3	96 - 113	49 - 58	178 - 209
Typhoon / Hurricane	4	114 - 135	59 - 69	210 - 249
Typhoon / Hurricane	5	135-	70-	249-

3.3.3 Definitions of approaching and landing typhoons

In order to compare the statistical data of tropical storm/typhoon between Japan and Cambodia, the definitions of terminologies used in this chapter are required. The definitions used for the typhoon in Japan is translated from the original website from JMA. However, for the definitions used for the typhoon in Cambodia are determined by the authors only for this study because there is no statistical data of typhoon available in Cambodia. Moreover, the data of typhoon landing and approaching Cambodia were counted by using the data provided by Joint Typhoon Center in which the scales (Saffir–Simpson hurricane wind scale) of wind speed used are different from that provided by JMA.

The definitions of the conventional terms "approaching typhoon" and "landing typhoon" are explained as follows.

❖ In Japan:

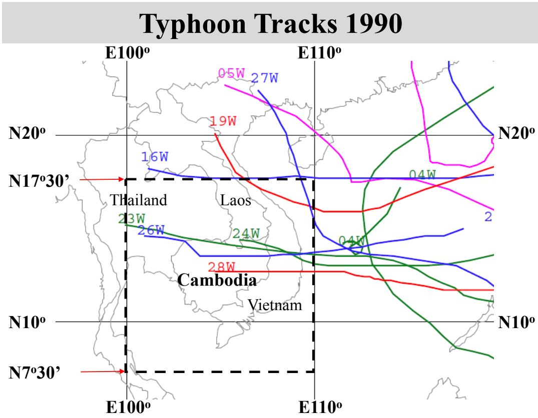
a) Approaching typhoon is the case where the center of typhoon enter the within 300 km from the meteorological station. The number of number of approaching typhoons also includes the number of landing typhoons.

b) Landing typhoon is the case where the center of typhoon has reached the coastline of the main islands of Japan such as Hokkaido, Honshu, Shikoku, and Kyushu. However, if the typhoon across a small island or peninsula and then out to the sea again in a short period of time it is considered as "pass-through".

❖ In Cambodia (refer to **Figure 3-6**)

a) Approaching typhoon is the case where the center of typhoon enter into the area with rectangular zone with the distance of approximately 300km from the Cambodian territory border. The number of number of approaching typhoons also includes the number of landing typhoons.

b) Landing typhoon is the case where the center of typhoon enter into Cambodia territory border.



Source: Prepared based a map of typhoon tracks provided by JTWC

Figure 3-6 Boundary for typhoon in Cambodia

Based on the definition, for example, in the **Figure 3-6** of typhoon track map recorded in 1990, there are totally six typhoons approaching to and four typhoons landing on Cambodia.

3.3.4 Typhoon in Japan

In Japan, typhoon is also one of the worst disasters, and causes extensive damages every year. Based on disaster database (EM-DAT, 2014), 34,657 people were killed and 7,863,945 people were affected by 150 typhoons. With the information from the homepage of Facts and Details, the most destructive typhoons in Japan since 1945 are described as follows. Makurazaki Typhoon in 1945 left 3,756 dead. Typhoon Kathleen in September 1947 was the largest post-war typhoon. It struck the Kanto area caused the banks of the Tonegawa and Arakawa rivers to overspill their banks, flooding 380,000 houses. About 1,900 people were killed. The Isewan (Ise Bay) Typhoon of 1950 caused the heaviest typhoon damage in Japan since the

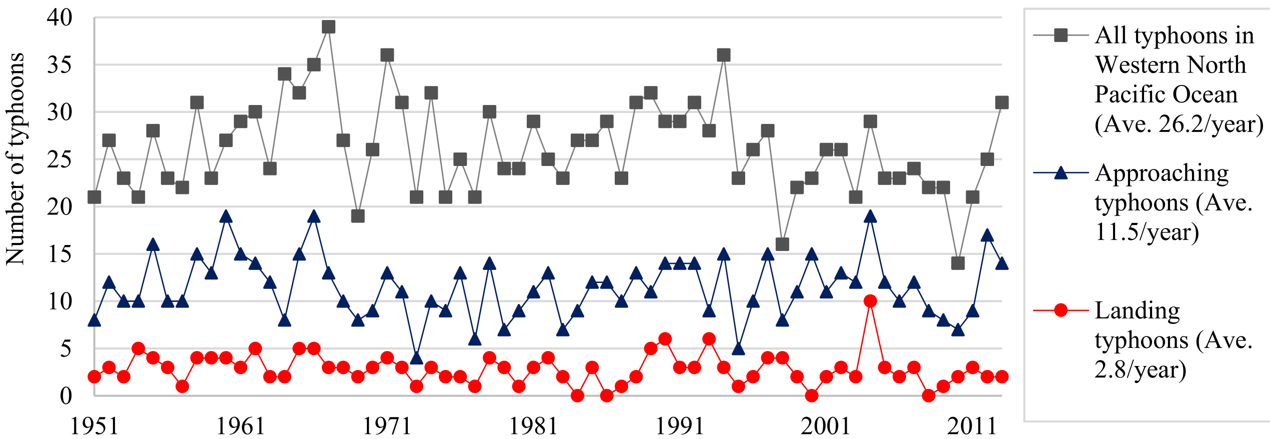


Figure 3-7 Number of typhoons approaching to and landing on Japan (1951-2013)

mid-1800s. The Isewan Typhoon was one of the most destructive ever which left 5,098 people dead or missing.

Based on the data provided by Japanese Meteorological Agency (JMA), the number of all typhoons occurred in North Western Pacific Ocean (hereinafter, referred to as Pacific Ocean) and number of typhoons approaching to and landing on Japan from 1951 to 2013 are plotted in the **Figure 3-7**. In average, the total number of 1,650 of typhoons occurred in the Pacific Ocean (Ave. 26.2 typhoons/year), while almost half of them approached to Japan with the number of 723 (Ave. 11.5 typhoons/year) and landed in Japan with the number of 178 (2.8 typhoons/year).

3.3.5 Typhoon in Cambodia

Cambodia has rarely affected by strong typhoons. Typhoons, originated in the Pacific Ocean, were always weakened or vanished on the way to pass surrounding countries, e.g., Philippine and Vietnam, before reaching Cambodia (see **Figure 3-8**). Based on disaster database (EM-DAT, 2014), there were only three typhoons hit Cambodia in which 44 people were killed and 178,091 people were affected. Typhoon becomes most damaging when it hits during the flooding season (September-October) as it causes heavy precipitation events.

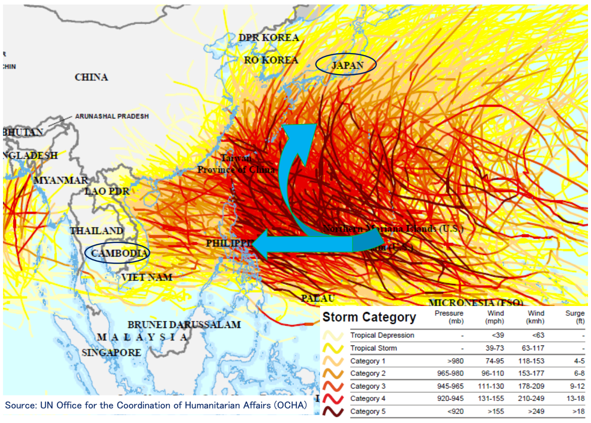
Recently, Typhoon Ketsana was the most severe typhoon which hit Cambodia on 29 September 2009. Typhoon Ketsana affected 14 out of 25 provinces of Cambodia, and it affected 180,000 households, killed 43 people and injured 67 people (Leng, H. A, 2014).

Based on the **Figure 3-9**, although Typhoon Ketsana did not make landfall in Cambodia, but its effect seems to be severe because the typhoon occurred during the peak rainy season so as it could easily induce flood event followed by typhoon. Moreover, because of the lack of awareness and preparedness against the typhoon and also most of houses are wooden and non-engineered houses which have no strength against the strong wind.

3.3.6 Statistical analysis of typhoon data in Cambodia

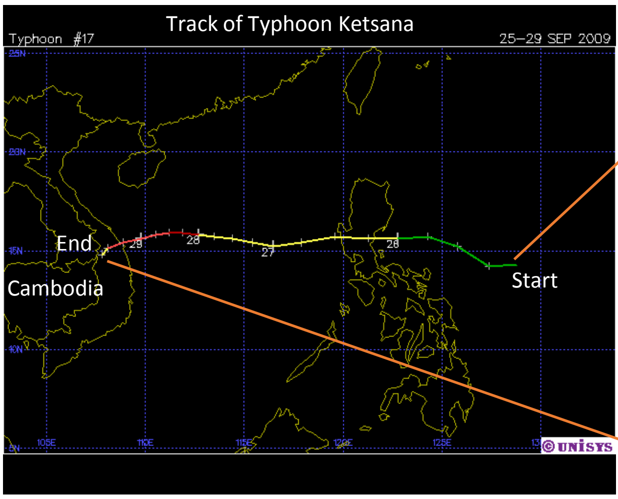
Based on the JTWC's databases, the statistical data of typhoon approaching to and landing on Cambodia were counted by using the above definitions of these two conventional terms. As shown in **Figure 3-10**, with the total number of 1,650 of typhoon occurred in Western North Pacific Ocean from 1951 to 2013, 165 typhoons have approached to Cambodia with the average of 2.6 typhoons/year) and 30 typhoons have landed on Cambodia with the average 0.5 typhoons/year. However, all of these typhoons landed on Cambodia varies within the scale of Tropical Depression to Tropical Storm.

In order to define the design condition considering the typhoon disaster in Cambodia, this section will analyze the wind speed data of typhoons landed on Cambodia to estimate the design wind speed with a return period of 50 years. And then, by using the estimated wind speed, the significant wave height ($H_{1/3}$) and significant wave period ($T_{1/3}$) could be estimated. The Weibul distribution was applied for the estimation of wind speed. And $H_{1/3}$ and $T_{1/3}$



Source: UNOCHA (modified)

Figure 3-8 Typhoon tracks in Asia Pacific Ocean (1956 – 2009)



Date: 25-29 SEP 2009
Typhoon #17

ADV	LAT	LON	TIME	WIND	PR	STAT
1	14.30	128.80	09/25/00Z	15	1010	TROPICAL DEPRESSION
2	14.20	127.40	09/25/06Z	20	1007	TROPICAL DEPRESSION
3	15.20	125.80	09/25/12Z	20	1007	TROPICAL DEPRESSION
4	15.70	124.30	09/25/18Z	30	1000	TROPICAL DEPRESSION
5	15.60	122.80	09/26/00Z	35	996	TROPICAL STORM
6	15.60	121.30	09/26/06Z	35	996	TROPICAL STORM
7	15.70	119.60	09/26/12Z	35	996	TROPICAL STORM
8	15.40	117.90	09/26/18Z	45	989	TROPICAL STORM
9	15.20	116.50	09/27/00Z	50	985	TROPICAL STORM
10	15.40	115.40	09/27/06Z	55	982	TROPICAL STORM
11	15.60	114.40	09/27/12Z	55	982	TROPICAL STORM
12	15.70	113.50	09/27/18Z	60	978	TROPICAL STORM
13	15.80	112.70	09/28/00Z	65	974	TYPHOON-1
14	15.90	111.90	09/28/06Z	80	963	TYPHOON-1
15	15.90	111.20	09/28/12Z	90	956	TYPHOON-2
16	15.80	110.50	09/28/18Z	90	956	TYPHOON-2
17	15.60	109.80	09/29/00Z	90	955	TYPHOON-2
18	15.40	108.90	09/29/06Z	90	956	TYPHOON-2
19	15.10	108.10	09/29/12Z	50	985	TROPICAL STORM
20	14.80	107.80	09/29/18Z	20	1007	TROPICAL DEPRESSION

Source: JTWC database provided by UNISYS

Figure 3-9 Typhoon Ketsana track and its detail information

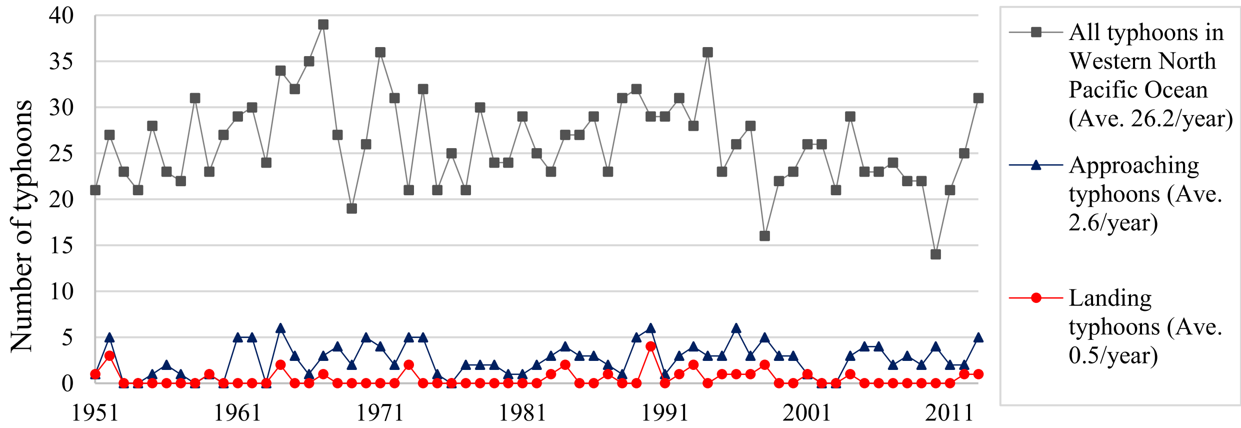


Figure 3-10 Number of typhoons approaching to and landing on Cambodia (1951-2013)

were estimated by using two different formulas: Pierson-Moskowitz Spectrum (indefinite fetch) and Matsuyasu Type II Spectrum (fetch-limited). The results from these two Spectral will be compared to define the most reasonable value which is close to the observed wind speed at Sihanoukville Port. The procedures of the analysis are described as follows:

(1) Estimation of return typhoon wind speed

The following procedures and formula for estimation of return typhoon wind speed considered based Goda (1985) sourced from Ministry of Transport (1999). Firstly, the maximum wind speed of landing typhoon on Cambodia among all the observed points provided by JTWC in every 6 hours was chosen. As shown above, the landing typhoons on Cambodia were totally 30 typhoons for the period between 1951 and 2013. However, those number of years that typhoons landed on Cambodia were 20. Therefore, the maximum wind speed of these 20 typhoons ranged from 15 to 55 kt were sued for the estimation. Secondly, short those maximum wind speed values from the highest to lowest one. Thirdly, the distribution of probability of non-exceedance for each wind speed data could was calculated.

This study considered maximum annual wind speeds of only landing typhoons for analysis, therefore, there are 20 wind speed data (15-55 knots) among the total of 30 landing typhoons in Cambodia were used. During statistical processing, the wind speeds are rearranged in the descending order (m-th), and the non-exceedance probability of each value was calculated using Weibul distribution (Goda, Y., 1985).

$$F[U \le x_{m,N}] = 1 - \frac{m-\alpha}{N-\beta}$$

where x_m : maximum wind speed at the m-th data ranged from 1 to number of data N (N=20); α, β parameters of distribution function, which shown in form of k(α, β) as follows: 0.75(0.54,0.64), 0.85(0.51,0.59), 1.0(0.48,0.53), 1.1(0.46,0.50), 1.25(0.44,0.47), 1.5(0.42,0.42), and 2.0(0.39,0.37).

The above parameters are determined in such a way that data give best fit to the distribution:

$$P[U \le x] = 1 - \exp[-\{(x-B)/A\}^k]$$

where A, B, k: parameters of distribution function.

In order to fit the data to the distribution function, the "non-exceedance probability" P is transformed into the variable r_v using the following equation.

$$r_v = [-\ln\{1 - P[U \le x]\}^{1/k}$$

If the data fit the above equation perfectly, then there will a linear relationship between x and r_v. Accordingly, equation for estimating the return wind speed is given as the following:

$$x = Ar_v + B$$

where parameters A, B are calculated by using least-squares method for correlation coefficient R. The case of k=2.0, $\alpha = 0.39, \beta = 0.37$ gave the largest R of 0.972.

As a result, peak wind speeds with their corresponding non-exceedance probability are shown the **Figure 3-11**.

The return per RP of the wind speed U is related to the non-exceedance probability P s in the following:

$$R_P = \frac{K}{N} \cdot \frac{1}{1 - P(U \le x)}$$

where K: number of years during the period for which analysis was carried out, K=63.

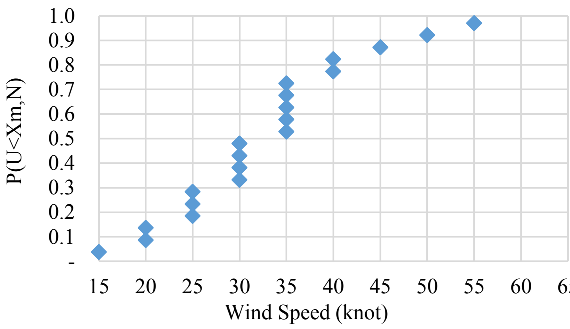


Figure 3-11 Non-exceedance probability of peak typhoon wind speed

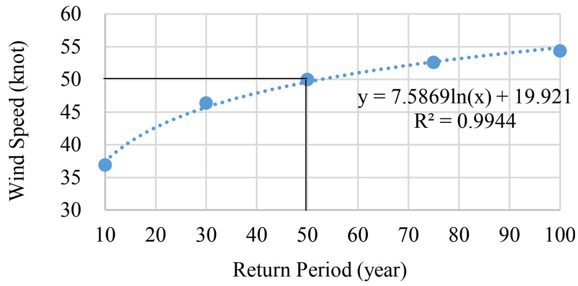


Figure 3-12 Estimated result of return period of peak typhoon wind speed

As a result, the return period of wind speeds are shown in **Figure 3-12**. The wind speed with a return period of 50 years was estimated to be 50 knots (25.7 m/s).

(2) Estimation of Wave Height and Wave Period

By using the above estimated wind speed of 25.7 m/s, the significant wave height and period were estimated by two different spectrum, Pierson-Moskowitz Spectrum and Mitsuyasu Type II Spectrum. The different consideration in these two spectrum is the consideration of fetch for the generated wave estimation.

1) Pierson-Moskowitz Spectrum

In Pierson-Moskowitz Spectrum, wave is assumed to be fully-developed and wind is blowing with indefinite fetch and duration. The following equations (Hattori, 1987) will calculate the spectrum in relation to frequency of wave:

$$s(f) = 8.10 \times 10^{-3}(2\pi)^{-4} g^2 f^{-5} *\exp\left\{-7.4\left(\frac{g}{2\pi U_{19.5}}\right)^{-5} f^{-4}\right\}(m^2.s)$$

$$U_{19.5}{=}U_{10}(1 + 5.75\sqrt{\gamma_{10}^2}\log\tfrac{z}{10}); \ (\gamma_{10}^2 = 1.6 \times 10^{-3})$$

U_{10}: typhoon wind speed at 10m height

where S(f): frequency spectrum
f: frequency (s)
U: wind speed (m/s)
g: gravitation acceleration, g=9.81 m/s2

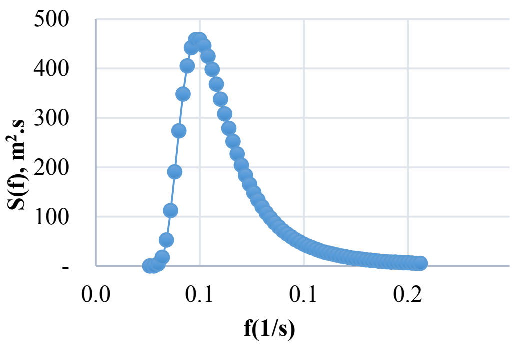


Figure 3-13 Wave frequency spectrum (Pierson-Moskowitz Spectrum)

Since the wind speed typhoon is observed at the height of 10 m, the wind speed at the height of 19.5 m which required in the above formula will be converted following the above relation. As a result, the frequency spectrum is estimated as shown in the **Figure 3-13**.

From the result of wave frequency spectrum, significant wave height ($H_{1/3}$) and wave period ($T_{1/3}$) are calculated by using the below equations (Hattori, 1987):

$$H_{1/3} = 4.004\eta_{rms} = 0.004\sqrt{E}$$

$$T_{1/3} = \frac{1}{1.05 f_P}$$

where E is wave energy, E is the summation of S(f)
f_p: peak frequency

As a result, Significant wave height ($H_{1/3}$) = 15.94 m/s and Significant wave period ($T_{1/3}$) = 18.67 s. The results seem to be overestimated because those values are too much higher than the observed data around Cambodia's seaport. The design value of $H_{1/3}$ = 2.4 m, $T_{1/3}$ = 5.6 m were suggested for the design of Cambodian seaport, which are estimated from wind speed data of at Sihanoukville Port (JICA, 1997).

2) Mitsuyasu Type II Spectrum

This Spectrum is limited to the fetch length which indicate the length of which the wind blow continuously on the sea surface. The fetch in this case can be varied from the local fetch length due to the geographic condition and also the length of typhoon radius which could be varied up to hundreds of kilometers.

By applying the estimated wind speed of 25.7 m/s, the Mitsuyasu Type II Spectrum is calculated using the below equations (Hattori, 1987):

$$s(f) = 8.58 \times 10^{-4}\left(\frac{gF}{u_*^2}\right)^{-0.312} g^2 f^{-5} *\exp\left\{-1.25 \times \left(\frac{gF}{u_*^2}\right)^{-1.32}\left(\frac{u_* f}{g}\right)^{-4}\right\}(m^2.s)$$

$$u_*{=}\sqrt{\gamma_{10}^2}U_{10}; \ (\gamma_{10}^2 = 1.6 \times 10^{-3})$$

U_{10}: typhoon wind speed at 10 m height

where S(f): frequency spectrum
F: fetch length (m)
u, U: wind speed (m/s)
g: gravitation acceleration, g=9.81 m/s2

As a result, the spectrum was shown in several of different fetch length varies from 10 km to 200 km. And the corresponding spectrum are shown in the **Figure 3-14** below. By applying the equations shown in Pierson-Moskowitz Spectrum, the significant wave height ($H_{1/3}$) and period ($T_{1/3}$) are estimated as shown in the **Table 3-5**.

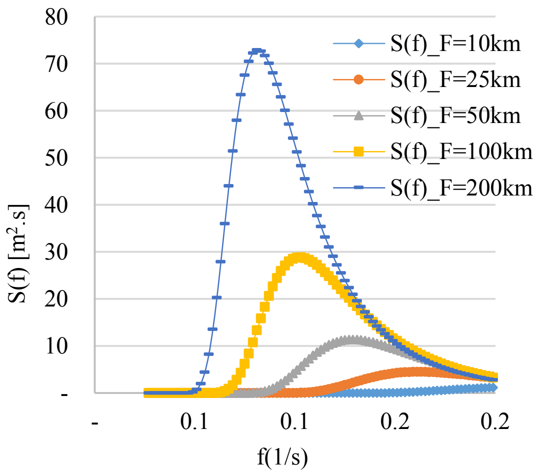


Figure 3-14 Wave frequency spectrum (Mitsuyasu Type II Spectrum)

By considering the local fetch around Cambodia's seaports, the local fetch length is estimated to be about 50 km. From the result shown in the **Table 3-5**, therefore, the $H_{1/3}$ and $T_{1/3}$ are estimated to be 3.9 m and 7.3 s respectively.

Table 3-5 Results of $H_{1/3}$ and $T_{1/3}$

F (km)	**10**	25	**50**	**100**	**200**
H1/3 (m)	1.8	2.8	**3.9**	5.6	7.9
T1/3 (s)	4.3	5.8	**7.3**	9.2	11.5

3.4 Flood

3.4.1 Flood in Japan

The following information regarding flood events in Japan is described in accordance with the studies in risk management of flood in Japan by Organization for Economic Cooperation and Development (OECD, 2006).

Japan has a geographic area of about 378, 000 square kilometers, which is divided between four main islands. The country has a temperate climate, subject to extensive regional variation, with three periods of heavy precipitation. Floods are frequent events and have caused great damage in the past. The country is fairly mountainous, and rivers are relatively short and steep. With a population of 127 million, population density is very high. Most residential and industrial areas tend to be located in lowland areas, along rivers; these areas are highly flood-prone.

Japan is exposed to all types of floods, in particular: storm surge, river floods, flash flood (result of continuous heavy rainfall and the soil is saturated), and Tsunami (by earthquakes, landslide or volcano eruption). The worst flooding in modern Japanese history was caused by the

Table 3-6 Significant flooding events in Japan, 2000-2004

Source: OECD, 2006

Event	Description	Economic loss		Human loss
		Insured loss	Total damage	
Tokai Heavy Rain, September 2000	Floods and landslides in the Nagoya area	USD 990 million (2001 value)	USD 7 billion**	18
Fukui Niigata-Fukushima Torrential Rain, July 2004	More than 12 500 hectares damaged, 5 800 homeless	USD 279 million	USD 1.95 billion	20 dead, 1 missing
Typhoon Songda/No. 18, September 2004	Winds up to 212 km/h, torrential rain	USD 3.59 billion*	USD 7.17 billion	41 dead, 4 missing*
Typhoon Meari/No. 21, September, 2004	Winds up to 160 km/h, rain, floods, landslides	USD 291 million	USD 798 million	26 dead, 1 missing
Typhoon Ma-On/No. 22, October 2004	Winds up to 162 km/h, rain, floods	USD 241 million	USD 603 million	7 dead, 4 missing
Typhoon Tokage/No. 23, October 2004	Winds up to 229 km/h, 23 210 houses destroyed	USD 1.12 billion	USD 3.2 billion	94 dead, 3 missing

** Figures from Japan Institute of Construction Engineering, n.a.
Source: Swiss Re, 2001 and 2005.

Ise-wan typhoon in 1959, which took more than 5,000 lives. It occurred at the end of a period of twenty-five years of extreme climatic conditions: in the years between 1934 and 1959, there were six flood disasters, mainly caused by typhoons, which killed between 1,000 and 3,000 persons each. In recent years, there have been several flooding events in Japan, including the Tokai Heavy Rain in 2000, as well as several events in 2004 related to the many typhoons which hit the country, most notably the typhoons Songda and Tokage (see **Table 3-6**). **Figure 3-15** show an example of torrential rains in Tokai region in 2000.

Based on disaster database (EM-DAT, 2014), 13,096 people were killed by 47 floods. Floods are frequent events and have caused great damage in the past, but the tendency of damages from floods has been decreasing by the development of technology for flood prevention measures. The effects from floods are severe for human lives and properties, but their effects are less for the ports in Japan because most of river ports are small ports. However, floods also have some effects on some seaports located the estuaries. However, flood level is normally less than tidal range.

Source: Cabinet Office, Japan, 2011

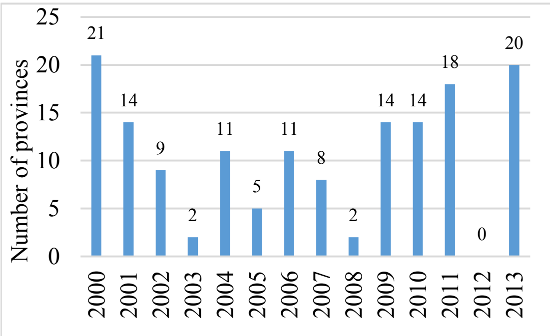
Figure 3-15 Torrential rains in Tokai region, 2000

3.4.2 Flood in Cambodia

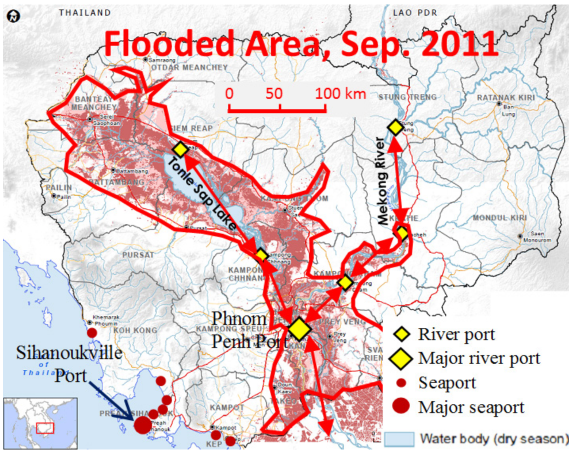
In Cambodia, flood frequently occurs and it is the most severe disaster which causes serious damages to human's lives and infrastructures. Flooding is one of the main natural disaster in Cambodia as 80 percent of the Cambodia's territory lies within the Mekong River. Cambodia floods claim lives of about 100 people annually and cause agricultural losses of 100 to 170 million USD each year (Leng H. A, 2014). Based on disaster database (EM-DAT, 2014), 18 major floods killed 1,421 people.

There were three major floods in Cambodia based on the record from 2000 to 2013 **(Figure 3-16)**. Based on Leng (2014), in 2011, floods affected 350,000 households (over 1.5 million people) and 52,000 households were evacuated. 18 out of 24 provinces in Cambodia were affected; 4 provinces along Mekong River and Tonle Sap were worst hit. 250 people lives were dead and 23 people sustained injuries in the floods in 2011. 431,000 hectares of transplanted rice fields were affected and 267,000 hectares of rice fields were damaged. 925 kilometers of the national, provincial and urban roads were affected and 360 kilometers of the roads were damaged. The 2011 floods caused an estimated loss at 630 million USD.

Flood in Cambodia can be divided in two main categories, flash flood and seasonal flood/Mekong flood.



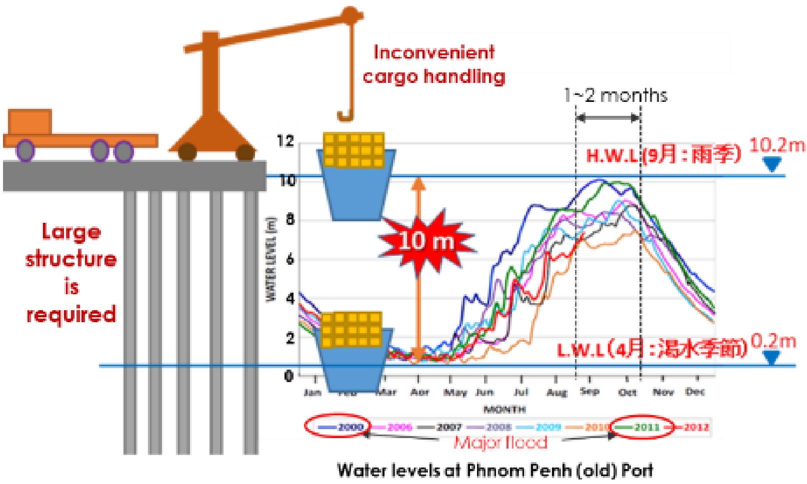
Source: data from NCDM provided in Leng (2014)
Figure 3-16 Number of (out of a total number 24) provinces affected by flood from 2000 to 2013



Source: prepared based on information from MPWT (2012) using flood extent map provided by WHO
Figure 3-17 Port network & flood extent in 2011

Source: Leng (2014)
Figure 3-18 Residential houses and national roads destroyed by flood

However, most of floods are found to occur in the combination of both floods when the heavy rainfall occur



(Water level provided in JICA, 2013)
Figure 3-19 Large seasonal water fluctuation cause difficulties in port construction and operation

during the water level of Mekong River is high. As shown in **Figure 3-17**, as an example of flood extent in 2011 which covers a large area and destroy transport network in Cambodia. Floods affect river ports which considered as an important transport mode in Cambodia, especially for the local people transporting their agriculture products to the markets as well distributing consuming goods from the city to the rural area. During the flooding period, roads are destroyed by floods from the flowing water across the roads and submerged in water for days (see **Figure 3-18**).

Furthermore, as shown in **Figure 3-19**, floods caused some difficulties in port operation due to the annual fluctuation water levels that varies from 0 m in dry season to around 10 m in rainy season. This much difference of water levels requires port facilities to have larger and stronger structure than its required capacity.

Flood in Japan is short period because the rivers are mostly short and steep. But in Cambodia flood periods prolong for several days because rivers are not steep and the most of Cambodia's geography consists of plains. So, the effects from floods are not major subjects in the design of port facilities in Japan. But, these effects are severe for ports in Cambodian, especially river ports.

3.4.3 Statistical analysis of flood data in Cambodia

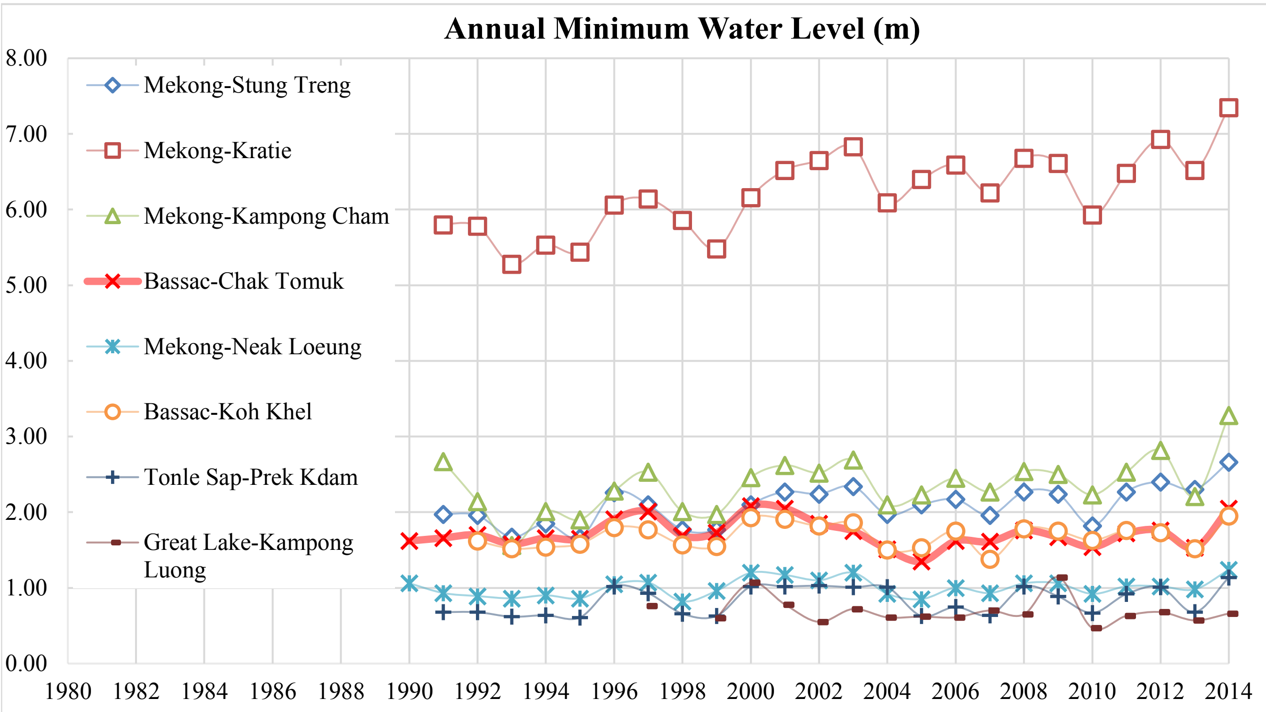
The maximum and minimum water level data recorded for the period of 20 to 30 years were provided by the Ministry of Water Resources and Meteorology (MOWRAM), Cambodia. The observation station of each

Source: MRC, Cambodia

Figure 3-20 Locations of observation station for water level data

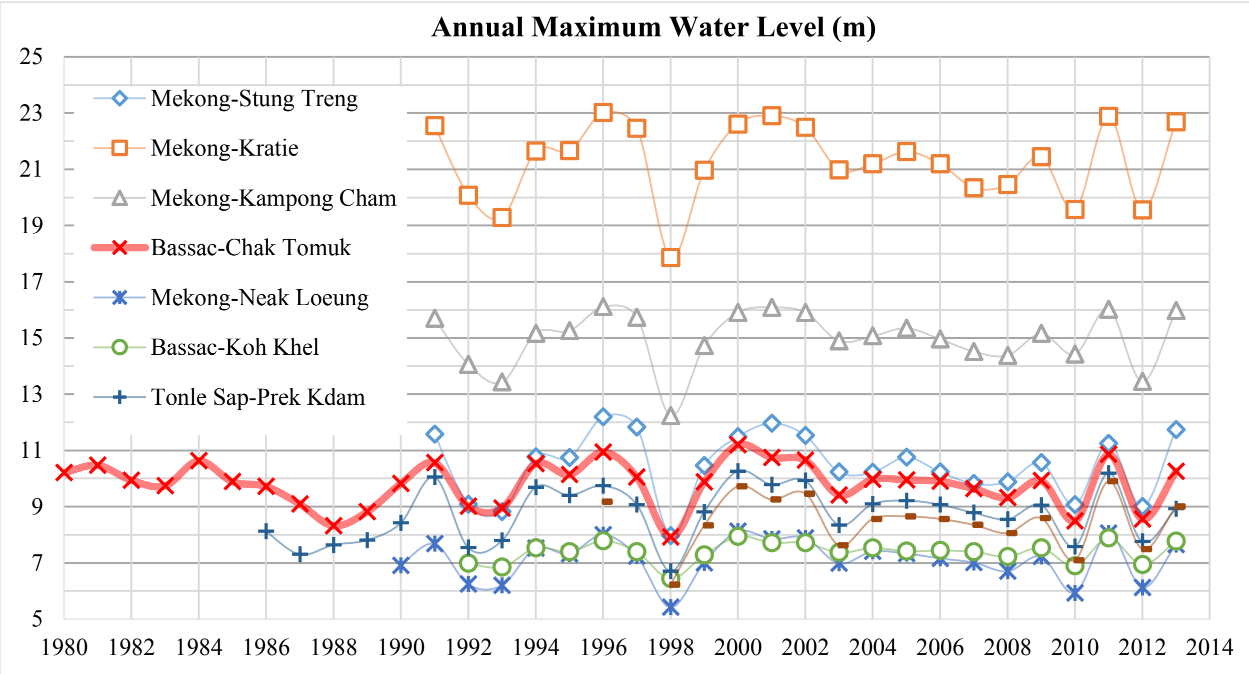
water level data are shown in **Figure 3-20** and the observed data of maximum and minimum are shown in **Figure 3-21** and **Figure 3-22**, respectively.

As shown in this **Figure 3-20**, 5 stations are located along Mekong River (Mekong-kratie, Mekong-Kampong



Source: MOWRAM, Cambodia

Figure 3-21 Trend of annual minimum water level



Source: MOWRAM, Cambodia

Figure 3-22 Trend of annual maximum water level

Cham, Bassac-Chak Tomuk, and Mekong-Neak Loeung), one station in Bassac River (Bassac-Koh Khel), and the last two are in Tonle Sap River (Tonle Sap-Prek Kdam) and Tonle Sap Lake (Great Lak-Kampong Cham). As observed from the graphs of both maximum and minimum water levels, the tendency or trend of water level each year are coincident to each other. However, for the analysis of flood water level, water data from Bassac-Chak Tomuk station was selected because this station is close to Phnom Penh Port.

Using annual maximum water level in Bassac-Chak Tomuk staion, the maximum flood water level with a return period of 50 years was estimated by applying Weibul distribution. The calculation process is the same to that applied for the wind speed estimation in section 3.3.6 (1). As a result, the probability of non-exceedance for the maximum water level data are shown in **Figure 3-22** below. The result of maximum flood water level with corresponding estimated return period of 17 years to 100 years (see **Figure 3-24**). As shown in **Figure 3-24**, the water levels with a return period of 30, 50, and 100 years were estimated to be equal to 11.43, 11.65, and 11.93 m, respectively.

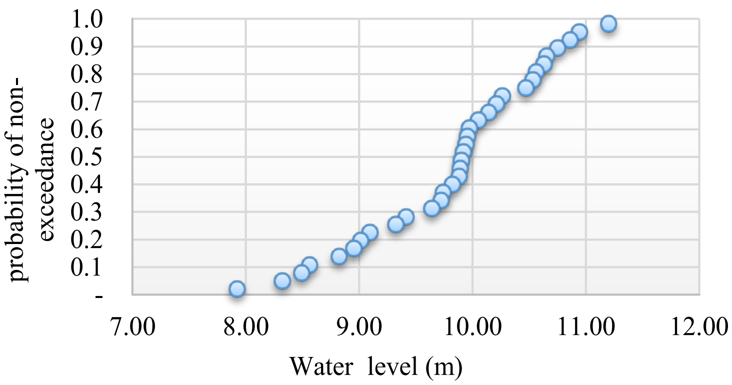


Figure 3-23 Probability of non-exceedance of maximum water level data

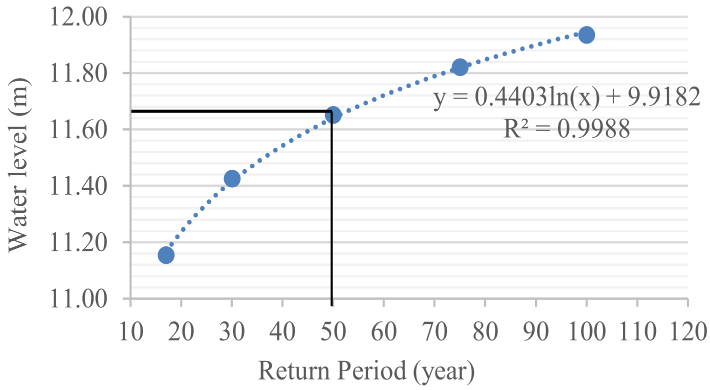


Figure 3-24 Result of maximum flood water level with corresponding return period

3.5 Design conditions of port facilities considering natural disasters

According to the above comparison of the natural disasters conditions between Japan and Cambodia, the effects on design conditions of port facilities in Cambodia are summarized in **Table 3-7**.

Based on the conditions of natural disasters in both country, the design conditions for port facilities are recommended for the design of port facilities in Cambodia. These design conditions will be used for the design of port facilities in Cambodia in the following chapter.

Table 3-7 Differences of design conditions for port facilities between Japan and Cambodia

Natural Disaster	Japan	Cambodia
Earthquake	Strong earthquake (Magnitude ≥ 5.0, max. 9.0) kh = 0.05 - 0.27	No earthquake kh ≤ 0.05
Typhoon	Frequent and severe Wind speed: up to 69 m/s or more (Category 5)	Rare and not severe Wind speed: less than 25.7 m/s (Tropical Storm)
Flood	Relatively affect ports located at estuaries. Usually smaller than tidal range	Severe and frequent and affect major river ports Range of water level: up to about 10 m

4 Evaluation of Suitable Structural Types of Port Facilities in Cambodia

4.1 Introduction

Quaywall commonly roles as a major port facility for handling of goods as well as mooring of ships. For ports in Cambodia, quaywall is considerably regarded as a major facility. The development of quaywall have been continuously developed in order to fulfil the rapid growth of country's economy. Concrete block type quaywalls have been adopted for Sihanoukville Port (largest seaport) while steel pipe pile type quaywalls have been adopted for Phnom Penh Port (largest river port). However, there is no research to prove that the adopted structure types for both ports are appropriately selected. Therefore, in this chapter, we attempt to evaluate the most appropriate structure type of quaywalls for both river port and sea port in Cambodia by considering mainly its natural disaster conditions. There are four different types of quaywalls were considered for the design calculation for the evaluation of suitable structure types as follows: concrete block, concrete caisson, steel pipe pile, and steel sheet pile. The selection of the suitable structure types is based on the comparison of three criteria, applicability against natural disaster conditions, construction cost, and constructability of each structural type.

4.2 Objective

The objective in this chapter is to evaluate the suitable structure types of port facilities for both seaport and river port in Cambodia. Four different types of quaywalls were considered in the evaluation: concrete block, concrete caisson, steel pipe pile, and steel sheet pile.

4.3 Scope of work

Several conditions may be considered in order to concretely evaluate the suitable structure types of quaywalls. However, in this study, the following three scope of works were carried out for evaluation of suitable structure type of quaywall of ports in Cambodia and compare with that of Japan.

(1) Design calculation of each structure against disaster conditions

The design calculation of each structure against the disaster conditions by varying the earthquake intensity (in calculation, earthquake intensity is represented by the "horizontal seismic coefficient, kh") from the minimum value of 0.05 (as for Cambodia case) to the maximum value of 0.27 (as for Japan case). The significant wave height estimated from typhoons was not considered because the studied structure is quaywall which water condition is normally calm and quaywall is protected by breakwaters. For flood, is considered for river port design by considering the flood water level and minimum water level into the design.

Considering the above conditions, the applicability of each structure type of quaywall in Cambodia and Japan will be discussed.

(2) Material cost comparison of each structure

The cost of each structure type of quaywall was calculated using the required dimensions of each structural type from the result calculated in first scope of work. Material unit prices in Cambodia were used in cost calculation, however, the material unit prices in Japan were used for the materials which are not available in Cambodia. The structural members of each structure type accounted for the calculation were: quantity of each structure itself, quaywall foundation work, backfill stone and sand, and separated structure for crane's rail foundation, except steel pipe pile structure. Finally, the cost of each structure type of quaywall were compared for the suggestion of suitable structure type of quaywall for seaport and river port in Cambodia.

(3) Comparison of constructability of each structure

Various factors may contribute to the constructability of each structure type. However, in this study, we considered major factors the comparison of constructability of each structure: heavy equipment, work vessel, skilled labour/engineer, and material supply. The evaluation of the above factors were attempted to carried out based the hearing survey, previous project of port development, study on the actual situation of construction condition in Cambodia. Nonetheless, due to the insufficient data for the analysis quantitatively, the result from this scope of work could be roughly considered in the evaluation of suitable structural types.

4.4 Design calculation of each structural type

4.4.1 Design code and design conditions

(1) Design code:

All design procedures for in the following analyses were performed by using the "Technical Standards and Commentaries for Port and Harbor Facilities in Japan" (Ministry of Transport, 1999).

(2) Design conditions

The design conditions regarding the natural disasters: earthquake, typhoon, and flood were considered based on the above analyzed results. For the other design conditions and parameters, we used design conditions of quaywall from the existing conditions used in the latest port development projects which were provided by the port authorities. The largest ports in Cambodia were

Table 4-1 Design conditions for seaport and river port

Conditions for quaywall design	Seaport	River Port
Crest height	+3.0 m	+9.5
Water depth	-13.5 m	-8.5 m
Ship size	50,000 DWT	5,000 DWT
Berthing speed	0.1 m/s (angle 10^o)	0.15 m/s (angle 10^o)
Berthing energy	330 kN.m	170 kN.m
Tractive force	1,000 kN	500 kN
Distributed load	30 kN/m^2 (ordinary condition) 15 kN/m^2 (earthquake condition)	Same as left
Quay Side Gantry Crane	Post-Panamax (span leg 20m, design load 780kN/wheel)	Below Panamax class (span leg 16m, design load 455kN/wheel)
Existing ground elevation	-8.6 m	-7.0
Sub-soil	N=0-5 (depth 0-4m) N=5-50 (depth 4-7m) N>50 (depth >7m)	N=0-5 (depth 0-10m) N=5-30 (depth 10-30m) N=30-50 (depth 30-40m)
Water levels	Highest Water Level (H.W.L): +1.43 m Mean Sea Level (MSL): +0.60 m Lowest Water Level (L.W.L): 0.00 m	Highest Water Level (H.W.L): +8.60m Mean Sea Level (MSL): 0.65 m Lowest Water Level (L.W.L): 0.00 m
Wave, current, river flow	Not considered	
Horizontal seismic coefficient	Kh = 0.05 – 0.27	

considered for this case study: Sihanoukville Port was considered as to represent the seaport and Phnom Penh New Port was considered as to represent the river port in Cambodia. The basic design conditions of both ports are listed in the **Table 4-1**.

4.4.2 Design calculation for concrete block quaywall

4.4.2.1 Cross section

The **Table 4-2** shows dimensions of concreted blocks for both seaport and river port that were assumed based design condition of Multipurpose Terminal Development Project of Sihanoukville Port. Each concrete block is assumed to be non-reinforced concrete (unit weight 22.6 kN/m^3) and the number of block layer is divided in to 7 layer equally, except the top layers. The cross section of concrete block quaywall of seaport (including rubble base and rubble backfill and filling material) were considered based on the detailed design report of a project in Sihanoukville Port. And, following that of seaport, cross section of river port was summed as shown **Figure 4-1**.

The below **Figure 4-1** shows the major different conditions in the design of seaport and river port. The design of seaport is for the relatively large size of ship of 50,000 DWT while that of river port is just 5,000 DWT. However, the structure for seaport is relatively smaller than that of river port. Moreover, due to a poor subsoil condition and existing river bed of river port, larger foundation for quaywall was assumed for river port.

Table 4-2 Dimension of concrete blocks

<table>
<tr><th rowspan="2">Block Layer</th><th colspan="5">Seaport</th><th colspan="5">River Port</th></tr>
<tr><th>Elevation of top (m)</th><th>Height (m)</th><th>Base (m)</th><th>Length (m)</th><th>Weight (tons)</th><th>Elevation of top (m)</th><th>Height (m)</th><th>Base (m)</th><th>Length (m)</th><th>Weight (tons)</th></tr>
<tr><td>Block 1</td><td>+3.0</td><td>2.0</td><td rowspan="7">2.0</td><td>6.7</td><td>60.57</td><td>+9.5</td><td rowspan="2">3.0</td><td rowspan="7">2.0</td><td>6.7</td><td>90.85</td></tr>
<tr><td>Block 2</td><td>+1.0</td><td rowspan="6">2.5</td><td>6.1</td><td>50.14</td><td>+6.5</td><td>6.1</td><td>82.76</td></tr>
<tr><td>Block 3</td><td>-1.5</td><td>6.5</td><td>58.76</td><td>+3.5</td><td rowspan="5">2.5</td><td>6.5</td><td>58.76</td></tr>
<tr><td>Block 4</td><td>-4.0</td><td>7.5</td><td>67.80</td><td>+1.0</td><td>7.5</td><td>67.80</td></tr>
<tr><td>Block 5</td><td>-6.5</td><td>8.5</td><td>76.84</td><td>-1.5</td><td>8.5</td><td>76.84</td></tr>
<tr><td>Block 6</td><td>-9.0</td><td>7.5</td><td>67.80</td><td>-4.0</td><td>7.5</td><td>67.80</td></tr>
<tr><td>Block 7</td><td>-11.5</td><td>7.5</td><td>67.80</td><td>-6.5</td><td>7.5</td><td>67.80</td></tr>
</table>

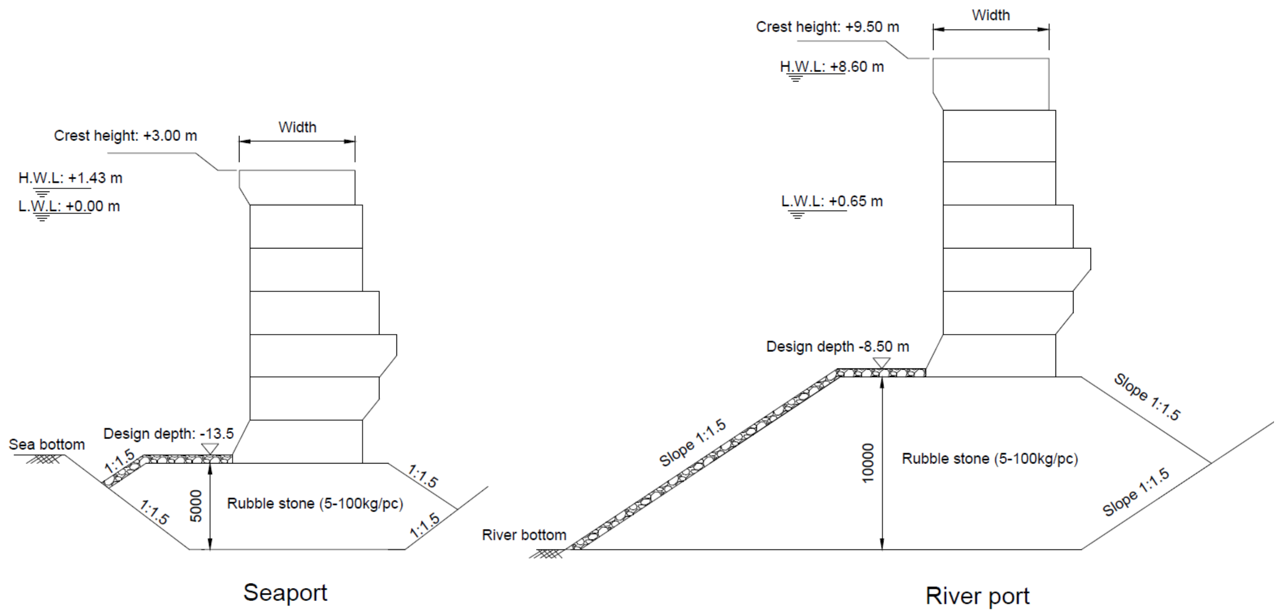


Figure 4-1 Example of cross sections of concrete block quaywall of seaport (left) and river port (right)

4.4.2.2 Examination of stability

According to the Japanese Technical Standards, in the examination of safety of concrete block quaywall, the safety factor of 1.5 or 1.2 in ordinary condition and 1.1 or 1.0 for extraordinary condition are suggested for the design against both sliding and overturning conditions. In this calculated we considered safety factor to be equal to 1.0 or over.

The examination of stability was performed considering the following criteria, based on the characteristic of required materials used for quaywall construction.

- Unit weight of backfilled material (above water): 18.00 kN/m^3
- Unit weight of backfilled material (in water): 10.00 kN/m^3
- Unit weight of precast concrete block for wall: 22.60 kN/m^3
- Angle of internal friction of backfill material: 40.00 deg.
- Angle of friction between backfilling material and backface of wall: 15.00 deg.
- Angle of batter of backface wall from vertical line: 0.00 deg.
- Angle of backfill ground surface from horizontal line: 0.00 deg.
- Coefficient of friction between concrete and concrete: 0.5
- Coefficient of friction between concrete and rubble stone: 0.6

4.4.2.3 Calculation procedure

In order to calculate the required dimension of each concrete block against the earthquake conditions, the following 3 steps were carried out:

Step 1: following the Japanese Technical Standards, external forces and loads acting on quaywall were calculated.

Step 2: calculate the safety factor (during ordinary and extraordinary conditions) against sliding and overturning of each concrete block by:

1) Varying the length of each concrete block by multiplying their original length to the following 13 cases of different coefficient: 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.5, 1.75, 2.0, 2.5, 3.0, 4.0 and 5.0.

2) In each case of varied length of concrete block, the safety factor of each block was calculated for each of the following 13 cases of the horizontal seismic coefficient: kh=0.05, 0.07, 0.09, 0.10, 0.11, 0.13, 0.15, 0.17, 0.19, 0.21, 0.23, 0.25, and 0.27.

Step 3: extract only the minimum safety factor among 7 block layer. Totally, there were 169 values of minimum safety factor for all the cases calculated in Step 2.

4.4.2.4 Calculation results and discussion

The analysis of structure stability against sliding and overturning were conducted in both permanent (without effect of earthquake) and variable conditions (with effect of earthquake). In ordinary conditions, the calculated coefficient for width of concrete block was equal to 0.65 for in case of sliding and 0.75 in cased of overturning. Conversely, the required width of concrete block is largely depending the earthquake condition. Therefore, only the results in earthquake conditions are shown and discussed.

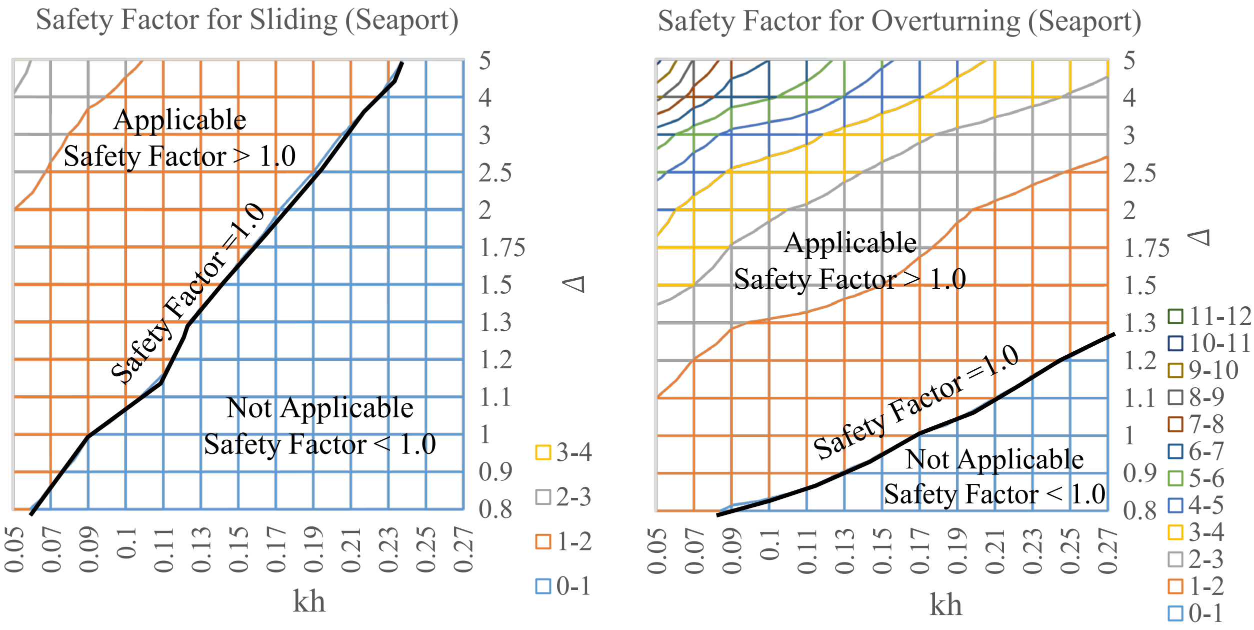


Figure 4-2 Safety factor concrete block of seaport against earthquake in sliding (left) and overturning (right)

From the calculation results in sliding condition, the minimum safety of the Block 6 was always calculated in each case. However, in the overturning conditions, the minimum safety factor was calculated found from the Block 6 and 7 alternatively.

Figure 4-2 and **Figure 4-3** show the safety factors of structure corresponding to kh value (horizontal axis) and the ratio of concrete block quaywall width (vertical axis).

In both ports, concrete block is critical for sliding (left). When width of block increased twice (about 13m width in average), it could resist to kh of 0.17 for seaport while kh of 0.19 for river port. From this result, it could be concluded that concrete block structure is suitable only for the region with low kh value such as Cambodia. Therefore, concrete block structural type is “applicable” in Cambodia, but not applicable in Japan.

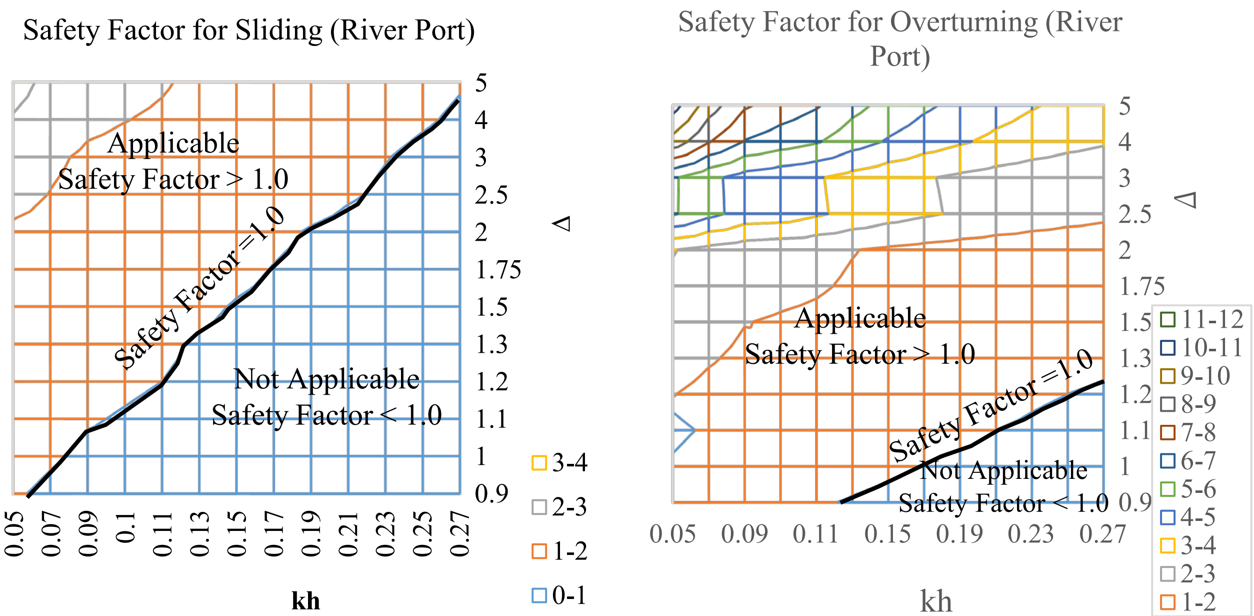


Figure 4-3 Safety factor concrete block of river port against earthquake in sliding (left) and overturning (right)

4.4.3 Design calculation for concrete caisson quaywall

4.4.3.1 Cross section

In addition to the design condition shown in **Table 4-1**, the detail design conditions for concrete caisson structure and its shape parameters are shown the **Table 4-3**. All the design conditions shown **Table 4-3** are same except the height of caisson excluding the height of super structure. The height of super structure was assumed to be 1.2 m for seaport and 1.0 m for river port and its sectional width is fixed to 6.0 m. In addition, the explanations of items in listed in **Table 4-3** are shown in the below **Figure 4-4**.

Table 4-3 Dimensions of concrete blocks

Input shape of caisson	Seaport	River Port
Width (m)	Calculated to enhance stability of quaywall	
Length (m)	15	Same as left
Height (m)	15.8	17.5
Bottom width (m)	0.6	Same as left
Wall thickness	0.4	Same as left
Caisson cover	0.3	Same as left
Hanch (m)	0.2	Same as left
Footing (m)	0.5	Same as left
Footing thickness	0.5	Same as left
Width of super structure (m)	7.7	Same as left
Thickness of super structure	1.2	1.0
Berm width (m)	5.0	Same as left
Slope of rubble base (m)	1:1.5	Same as left

4.4.3.2 Examination of stability

According to the Ministry of Transport (1999), in the examination of safety of concrete block quaywall, the safety factor of 1.2 in ordinary condition and 1.1 for extraordinary condition are suggested for the design against both sliding and overturning conditions. However, in order to keep consistency between concrete block and concrete caisson structure in the comparison, safety factor for both sliding and overturning were considered to be equal to 1.0 or over.

The examination of stability was performed considering the following criteria, based on the characteristic of required materials used for quaywall construction.

- Unit weight of backfilled material (above water): 18.00 kN/m^3
- Unit weight of backfilled material (in water): 10.00 kN/m^3
- Unit weight of RC (Reinforced Concrete) concrete for wall: 24.00 kN/m^3
- Angle of internal friction of backfill material: 40.00 deg.
- Angle of friction between backfilled material and backface of wall: 15.00 deg.
- Angle of batter of backface wall from vertical line: 0.00 deg.
- Angle of backfill ground surface from horizontal line: 0.00 deg.
- Coefficient of friction between concrete and rubble stone: 0.6

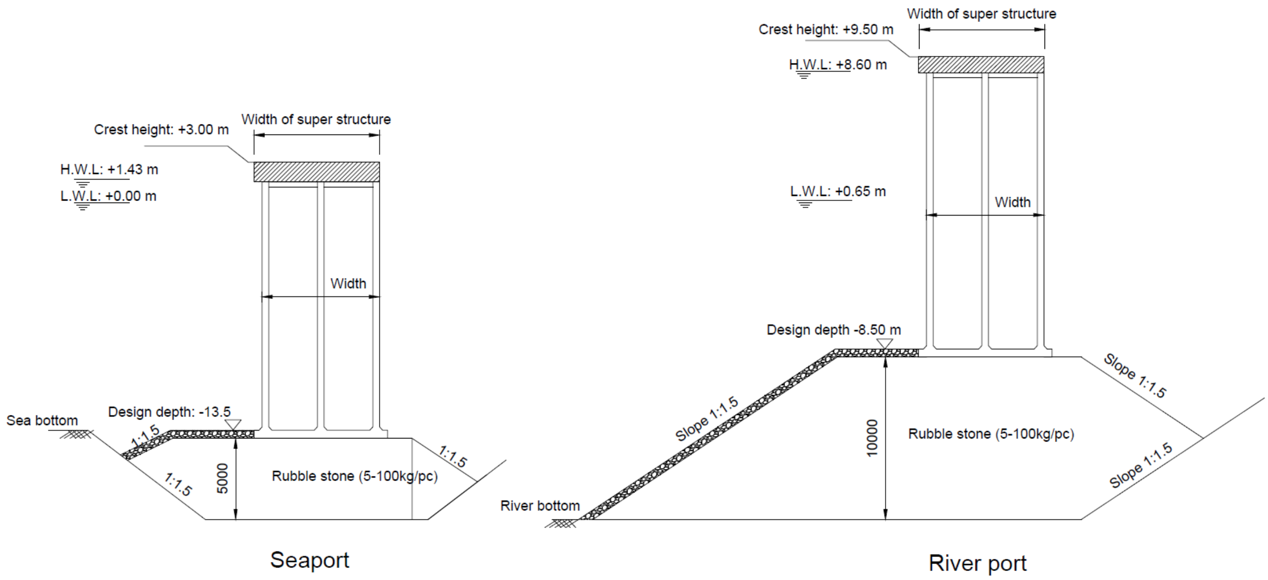


Figure 4-4 Example of cross sections of concrete caisson quaywall of seaport (left) and river port (right)

4.4.3.3 Calculation procedure

In order to calculate the required "width of caisson" against the earthquake conditions, the following 3 steps were carried out:

Step 1: following the Japanese Technical Standards, external forces and loads acting on quaywall were calculated.

Step 2: by fixing the length (L) of caisson to 15.0 m and fixing the maximum length of caisson compartment (in width direction) to 0.5 m. Therefore, if the length of compartment calculated to be larger than its maximum value, the number compartment will increased one more compartment.

Step 3: by fixing safety factor to be at least 1.0, the required width of caisson is calculated to meet the stability condition for both sliding and overturning.

4.4.3.4 Calculation Results and Discussion

(1) Stability of caisson type structure against Earthquake condition

The analysis of structure stability against sliding and overturning were conducted in both permanent (without effect of earthquake) and variable conditions (with effect of earthquake). As a result, the width of caisson in the permanent condition is constant and its value is smaller than that in the variable condition. Therefore, the results will be discussed only for the case in variable condition. The results the caisson width varies depending on the on the value of kh, which required to enhance the stability in both sliding and overturning conditions. However, the caisson is critical for its stability against earthquake in sliding condition comparing to that of overturning condition.

For the case of seaport, as shown in the **Figure 4-5 (top),** the effect from earthquake to the stability of structure can be categorized into two. In case of kh = 0.05 – 0.15, the width of caisson is increased linearly from 7.2 m to 11.5 m. In case of kh higher than 0.15, the required width of caisson is increased sharply up to 36.9 m (as for the case of kh=0.25). However, the caisson structure is not stable in case of kh = 0.27.

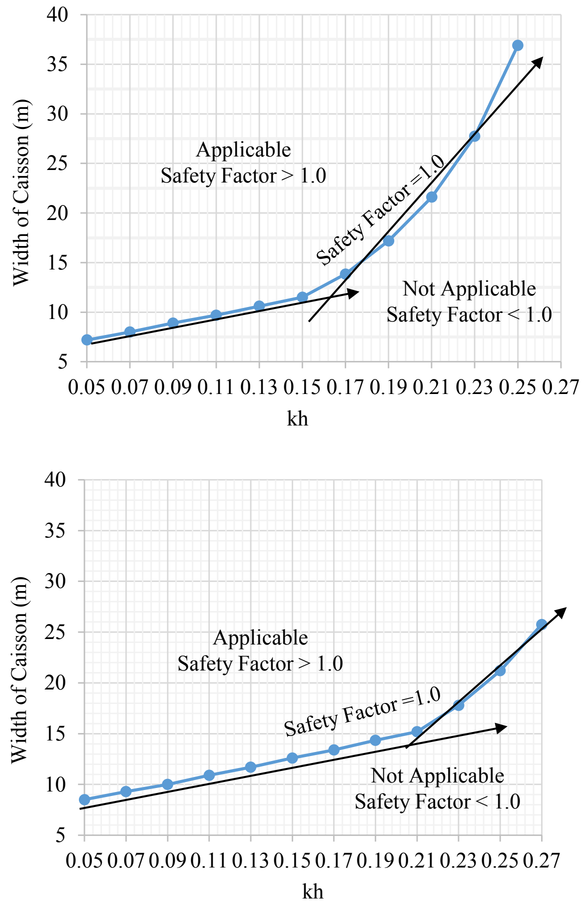


Figure 4-5 Calculation results of concrete caisson of seaport (top) and river port (bottom)

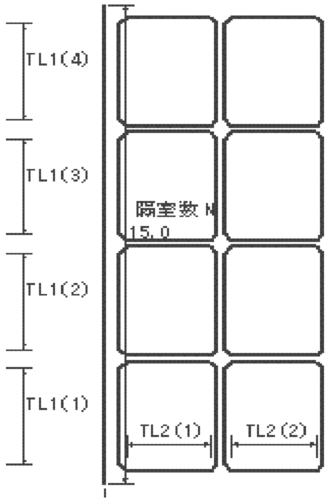
Table 4-4 Details of dimensions of caisson for each case of kh value (seaport)

kh	Width B (m)	TL2-1	TL2-2	TL2-3	TL2-4	TL2-5	TL2-6	TL2-7	TL1-1~4
0.05	7.2	2.7	2.7	NR	NR	NR	NR	NR	4.2
0.07	8	3.1	3.1	NR	NR	NR	NR	NR	4.2
0.09	8.9	3.55	3.55	NR	NR	NR	NR	NR	4.2
0.11	9.7	3.95	3.95	NR	NR	NR	NR	NR	4.2
0.13	10.6	4.4	4.4	NR	NR	NR	NR	NR	4.2
0.15	11.5	4.85	4.85	NR	NR	NR	NR	NR	4.2
0.17	13.85	3.8	3.85	3.8	NR	NR	NR	NR	4.2
0.19	17.2	4.9	5	4.9	NR	NR	NR	NR	4.2
0.21	21.6	4.65	4.65	4.65	4.65	NR	NR	NR	4.2
0.23	27.75	4.8	4.85	4.85	4.85	4.8	NR	NR	4.2
0.25	36.9	4.55	4.6	4.6	4.6	4.6	4.6	4.55	4.2
0.27	NG								

NR: Not required

Table 4-5 Details of dimensions of caisson for each case of kh value (river port)

kh	Width B (m)	TL2-1	TL2-2	TL2-3	TL2-4	TL2-5	TL1-1~4
0.05	8.5	3.35	3.35	NR	NR	NR	4.2
0.07	9.3	3.75	3.75	NR	NR	NR	4.2
0.09	10	4.1	4.1	NR	NR	NR	4.2
0.11	10.9	4.55	4.55	NR	NR	NR	4.2
0.13	11.7	4.95	4.95	NR	NR	NR	4.2
0.15	12.6	3.4	3.4	3.4	NR	NR	4.2
0.17	13.4	3.6	3.8	3.6	NR	NR	4.2
0.19	14.35	3.95	4.05	3.95	NR	NR	4.2
0.21	15.2	4.2	4.4	4.2	NR	NR	4.2
0.23	17.8	5.1	5.2	5.1	NR	NR	4.2
0.25	21.2	4.55	4.55	4.55	4.55	NR	4.2
0.27	25.75	4.4	4.45	4.45	4.45	4.4	4.2



NR: Not required

For the case of river port, as shown in the **Figure 4-5 (bottom)**, the effect from earthquake to the stability of structure can be categorized into two. In case of kh = 0.05 – 0.21, the width of caisson is increased linearly from 8.5 m to 15.2 m. In case of kh higher than 0.21, the required width of caisson is increased sharply up to 25.75 m (as for the case of kh=0.27).

From the above results, it could be concluded that the concrete caisson structure is applicable for the region with low (e.g., Cambodia) to moderate earthquake intensity (e.g., some parts of Japan), but it is not applicable for the region with high earthquake intensity (some parts of Japan).

(2) Details of dimensions of caisson for each corresponding width

The calculation was carried out for one f of caisson with fixed length of 15 m and 4 compartments (TL1(1) – TL1(4)) in the quaywall direction. From the direction of seaside to landside, the number and dimension of compartments are varied following the each corresponding width of caisson. The length of compartment TL2 is set to have maximum limit of 5.0 m. If the length of any TL2 is larger than this limit, the number of compartment will be increased one compartment. The details of number and dimension of each corresponding width of caisson for the case are shown in **Table 4-4** for the case of seaport and **Table 4-5** for the case of river port. The length shown in the above tables are in m and NR indicates that the compartment is not required.

In case of seaport (Table), only 2 compartments are required for the case of kh = 0.05 – 0.15 while 7 compartments are required for the case of kh = 0.25.

In case of river port (Table), only 2 compartments are required for the case of kh = 0.05 – 0.13 while 6 compartments are required for the case of kh = 0.27.

4.4.4 Design calculation for steel pipe pile quaywall

4.4.4.1 Cross Section

In accordance with the design conditions of seaport and river port as shown in **Table 4-1**, the cross sections of quaywall structures are considered as indicated in the below **Figure 4-6**.

For seaport, it requires to have width of 26.0 m in which 20.0 m design considering the foundation of the crane's rail. Less number of piles is used at seaport because the tips of piles could reach the hard bed rock. Therefore, a rahmen of steel pile structure of 26.0 by 20.0 m is considered in the design of seaport.

For river port, is requires to have the width of 22.0 m in which 16.0 is required for the span of crane's rail. Due to relatively poor subsoil condition, the number of pile is larger than that used for seaport because pile tips could not reach hard. Therefore, a rahmen of steel pile structure of 22.0 by 16.25m was considered for the design of river port.

4.4.4.2 Examination of Stability

According to the Japanese Technical Standards, steel pipe structure shall be designed to have minimum safety factor of bearing capacity of pipe to satisfy the following value in **Table 4-6**.

In addition to the design conditions shown in **Table 4-1**, the design conditions and parameters for steel pipe pile structure are shown as follows:

Slope of soil surface layer below quaywall: 1:2
Steel pipe specification: SKK490
Minimum pile diameter: 700 mm
Maximum pile diameter: 1,200 mm

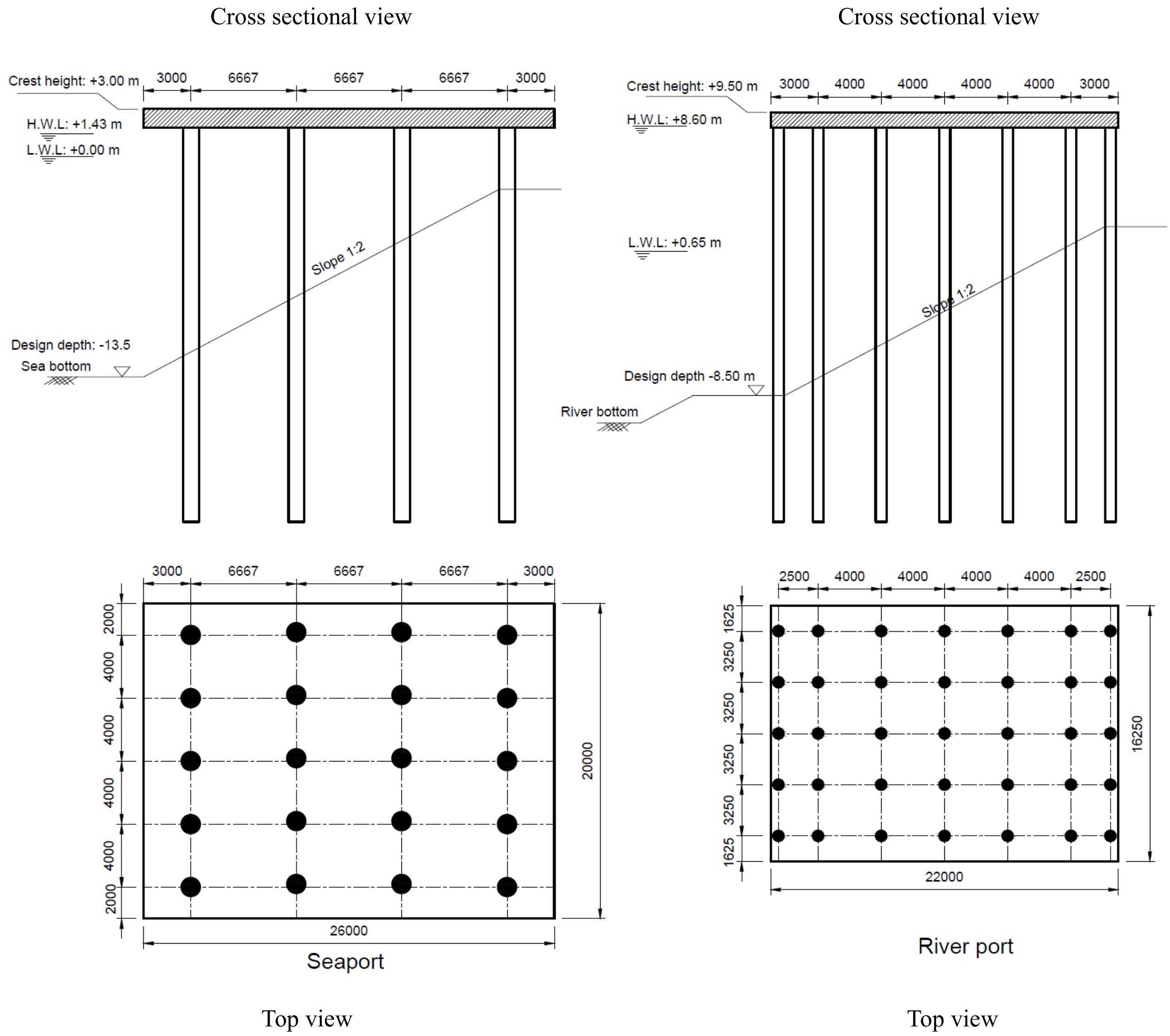


Figure 4-6 Cross section of steel pipe structure of seaport (left) and river port (right)

Minimum pile wall thickness:	10 mm
Maximum pile wall thickness:	25 mm
Corrosion allowance:	1 mm
Ship traction force:	1,000 kN×2

Table 4-6 Design safety factor

	Conditions		Safety Factor
Push condition	Permanent		2.5
	Variable	Tip supporting pile	1.5
		Friction supporting pile	2.0
Pull-out condition	Permanent		3.0
	Variable		2.5

4.4.4.3 Calculation Procedure

In order to calculate the required dimensions of steel pipe against the natural disaster conditions, the following 3 steps were carried out:

Step 1: following the Japanese Technical Standards, external forces and loads acting on quaywall were calculated.

Step 2: assumption of the pile cross section. The bearing capacity of pile was considered following the Japanese Industrial Standards (JIS).

Step 3: elastic design of assumed pile cross section against the acting forces in both permanent and variable conditions. If the required safety factors are satisfied, the cross sections are decided. But, if not, the cross sections of piles required to be changed and then the calculation will be repeated from Step 2.

4.4.4.4 Calculation Results and Discussion

The calculation results of steel pipe pile structure are expressed as the weight of used pipe which are calculated from the three dimensions of pile: diameter, wall thickness, and length.

For the case of seaport, the pile wall thickness varies from 9 mm to 13 mm and pile length varies from 24.5 m to 28.0 m and pile diameter varies from 800 mm to 1,100 mm. Only the pile diameter and pile weight are shown in the below **Figure 4-7**. However, only the pile weight could express the volume of pile required for each value of kh. As shown in **Figure 4-7 (top),** for kh = 0.05 – 0.13, the pile volume is almost constant with the value of 4.12 tons/m (for 1 m length of quaywall). For kh = 0.13 – 0.27, the pile weight steadily increased up to 6.46 t/m (for 1 m length of quaywall). Therefore, only about 1.67 times of pile weight is increased when kh is increased up to 0.27.

For the case of river port, the pile wall thickness varies from 7 mm to 9 mm and pile length varies from 30.0 m to 34.0 m and pile diameter varies from 600 mm to 800 mm. Only the pile diameter and pile weight are shown in the **Figure 4-7.** However, only the pile weight could express the volume of pile required for each value of kh. As shown in **Figure 4-7 (bottom),** for kh = 0.05 – 0.11, the pile volume is almost constant with the value of 7.3 tons/m

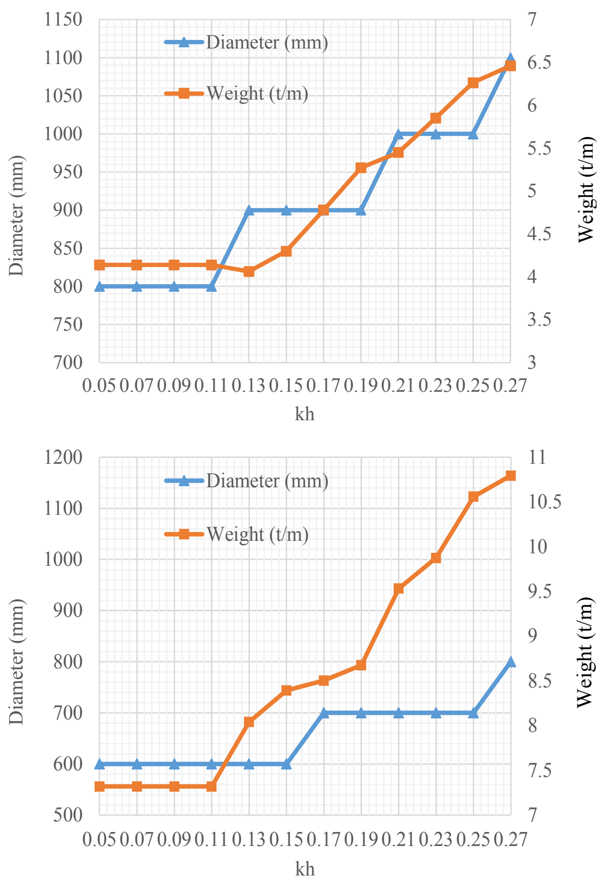


Figure 4-7 Calculation results of steel pipe pile structure for seaport (top) and river port (bottom)

(for 1 m length of quaywall). For kh = 0.13 – 0.27, the pile weight steadily increased up to 10.8 t/m (for 1 m length of quaywall). Therefore, only about 1.48 times of pile weight is increased when kh is increased up to 0.27.

Based on these two case, it could be concluded that the steel pile structure is highly resist against the earthquake. Therefore, this structural type is applicable for the region with high earthquake intensity such as Japan.

4.4.5 Steel sheet pile (seaport only)

4.4.5.1 Cross Section

The calculation of steel sheet pile structure was carried only for the case of seaport. In accordance with the design conditions of seaport as shown in **Table 4-1**, the cross section of quaywall structure are considered as shown in **Figure 4-8.** The cross section of steel sheet pile was considered to have two separated different structure types: ①steel sheet pile consists of front sheet pile, tie rod, and coupled-pile anchorage structure and ②steel pipe pile structure was considered for the crane rail foundation. The design calculation was carried out only for the case of ①, but for the case of ② the dimension of the two piles below the crane rail resulted from the above design calculation of the steel pipe pile structure.

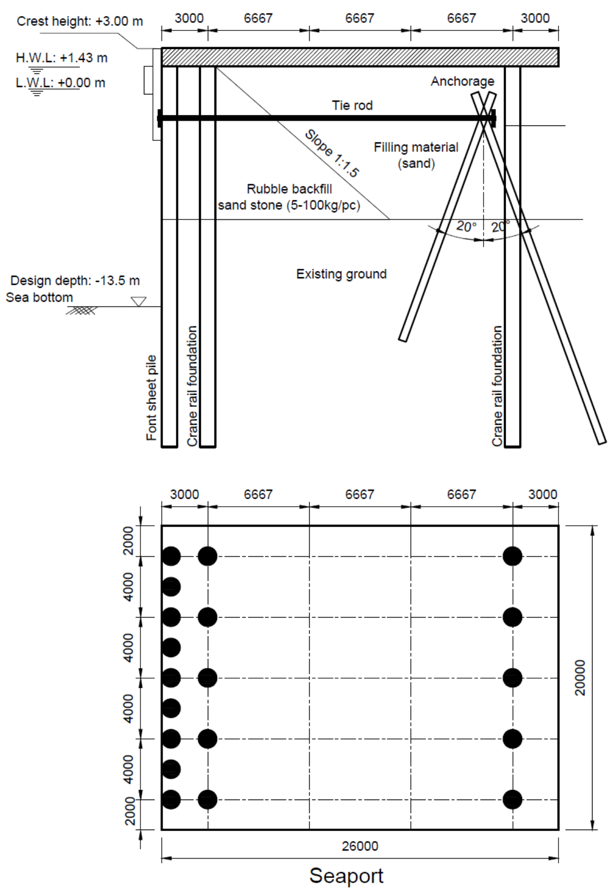


Figure 4-8 Example of cross section of steel sheet pile quaywall (seaport)

4.4.5.2 Examination of stability

According to the Ministry of Transport (1999), steel sheet pile structure shall be designed to have minimum safety factor of bearing capacity of pipe that satisfy the following value in **Table 4-7**:

Table 4-7 Design safety factor

	Permanent condition	Earthquake condition
Front Sheet Pile	1.5	1.2
Anchorage Pile (push)	2.5	1.5
Anchorage Pile (pull-out)	3.0	2.5

The steel pipe was chosen for the front sheet pile because its high strength is required for resistant against the shear stress from the soil and residual water pressure. And the H-shaped pile was chosen for the anchorage structure, C-shaped steel was chosen for the waling, and high strength tie rod HT690 with length of 20 m was chosen for the design. As shown in the below table, the corrosion allowance was considered for the design service life of structure of 30 years. The properties of materials used in the design are shown in **Table 4-8**.

Table 4-8 Steel materials and their properties

Component		Sheet pile	Anchorage pile (seaside)	Anchorage pile (landside)	Waling	Tied rod
Material		Pipe-L65 SKY490	H-SS400	H-SS401	C-SS400	HT690, Lenght20m
Corrosion margin allowance		1.8	1.5	1.5	0	1.5
Allowable stress	Ordinary	185	140	140	140	176
	Earthquake	277.5	210	210	210	210

4.4.5.3 Calculation Procedure

In order to calculate the required dimensions of steel sheet pile against the earthquake conditions, the following 3 steps were carried out:

Step 1: following the Japanese Technical Standards, external forces and loads acting on quaywall were calculated.

Step 2: assumption of the pile cross section. The pile stress was considered following the Japanese Industrial Standards (JIS).

Step 3: the stress intensity of resulting from the acting forces was calculated and this stress intensity will be used to compare with allowable stress intensity of the corresponding steel materials as listed in the above **Table 4-8**. Therefore, the dimension of each steel materials was considered with the condition that the calculated stress is less than the allowable stress.

4.4.5.4 Calculation results and discussion

The major steel material used in this structure is the steel pipe of front sheet pile. Each pipe was continuously connected and tied to the anchorage structure by tie rod. As shown **Figure 4-9**, the calculation results of diameter of this pipe varies from 1,000 mm to 1,200 mm following the increasing kh value from 0.05 to 0.27. The weight of the front sheet pile was express in 1 meter length of quaywall, 13.76 t/m for the case of kh = 0.05 – 0.11, 14.68 t/m for the case of kh = 0.13, 15.03 t/m for the case of kh = 0.15 – 0.21, 15.57 t/m for kh = 0.23 – 0.25, and 16.34 t/m for the case of kh = 0.27.

According to the above result, the increasing of the weight following the kh values is small. It is only about 1.18 times of difference of weight between the case of 0.05 and 0.27. It is concluded that the effect from earthquake on this structural type is small. Therefore, the steel sheet pile structure is applicable for the region with high earthquake intensity such as Japan.

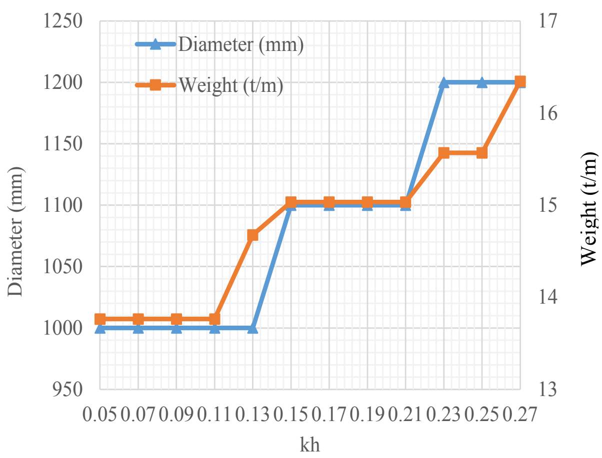


Figure 4-9 Calculation results of steel sheet pile structure

4.4.6 Applicability of each structure type of quaywall

According to the calculation results of each structural type of quaywall, this section will summary the applicability of each structural type of quaywall for seaport and river port in Cambodia and seaport in Japan. The kh value is divided into three categories, kh = 0.05 as for the case of Cambodia and for kh = 0.15 and 0.27 as for the case of Japan. The applicability of each structural type of quaywall are summarized in the **Table 4-9.**

Table 4-9 Summary of applicability of each structural type of quaywall

	Concrete Block	Concrete Caisson	Steel Pipe Pile	Steel Sheet Pile
0.05 (Cambodia)	A	A	A	A
0.15 (Japan)	A	A	A	A
0.27 (Japan)	NA	NA	A	A

A: Applicable; NA: Not applicable

4.5 Calculation of construction cost of each structure

4.5.1 Material unit price

Basically, the unit of price of material in Cambodia was considered for the cost calculation. However, for those materials which are not available in Cambodia, the unit price in Japan will be applied. The unit price in Cambodia was obtained from a JICA's report (JICA, 2012) while the unit price of material in Japan was obtained from the material price of construction materials in Japan published in 2012 (RIBC, 2012).

As shown in **Table 4-10**, the price shown in the red rectangular box indicates the price used in the cost calculation. And the price with yellow hatch indicates the cheaper price comparing between Cambodia and Japan. However, the unit price of plain concrete and steel bar are not much different between Cambodia and Japan. But, the unit price of sand in Cambodia is about 4.71 times cheaper than that in Japan. This much difference of price of sand, could affect the total material cost of each structure, especially for the case of caisson because a large volume of sand is used for filling the caisson.

4.5.2 Cost calculation and comparison

The cost of each structural type was calculated according to the quantity of materials required for corresponding to each case of kh value. The items to be considered for the cost calculation of each structure type are explained as follows:

(1) The cost of required materials for each quaywall structure according to the design calculation results shown in the above **Section 4.4**.

(2) Dredging work for quaywall foundation (only applied for the case of concrete block and concrete caisson structures).

(3) The rubble stone for quaywall foundation (only applied for the case of concrete block and concrete caisson structures).

(4) Structure of foundation of crane rail for quay side gantry crane (applied to all structural types, except steel pipe pile structure). For simplicity, the third pile (counting from the seaside to landside direction) of steel pipe pile structure quaywall was considered as the foundation of concrete block and caisson structures. As for the pipes for foundation of steel sheet pile structure, the second and third piles of steel pipe pile structure quaywall were considered as the foundation.

Table 4-10 List of unit price of materials used

Material	Unit	In Cambodia	In Japan
Plain Concrete	￥/m3	8,900	12,000
Reinforced Concrete	￥/m3	NA	20,000
Steel bar	￥/t	79,500	55,000
Sand	￥/m3	850	4,000
Rubble Stone (5-100 kg/piece)	￥/m3	2,300	NA
Dredging quay foundation	￥/m3	750	NA
Pavement	￥/m2	NA	9,000
Anti Corrosion	￥/m2	NA	5,000
Steel Pipe	￥/t	NA	122,000

Legends:

Cheaper price

Price used for cost calculation

NA: Not Available

* Currency conversion rate: 1$ = 100 Yen

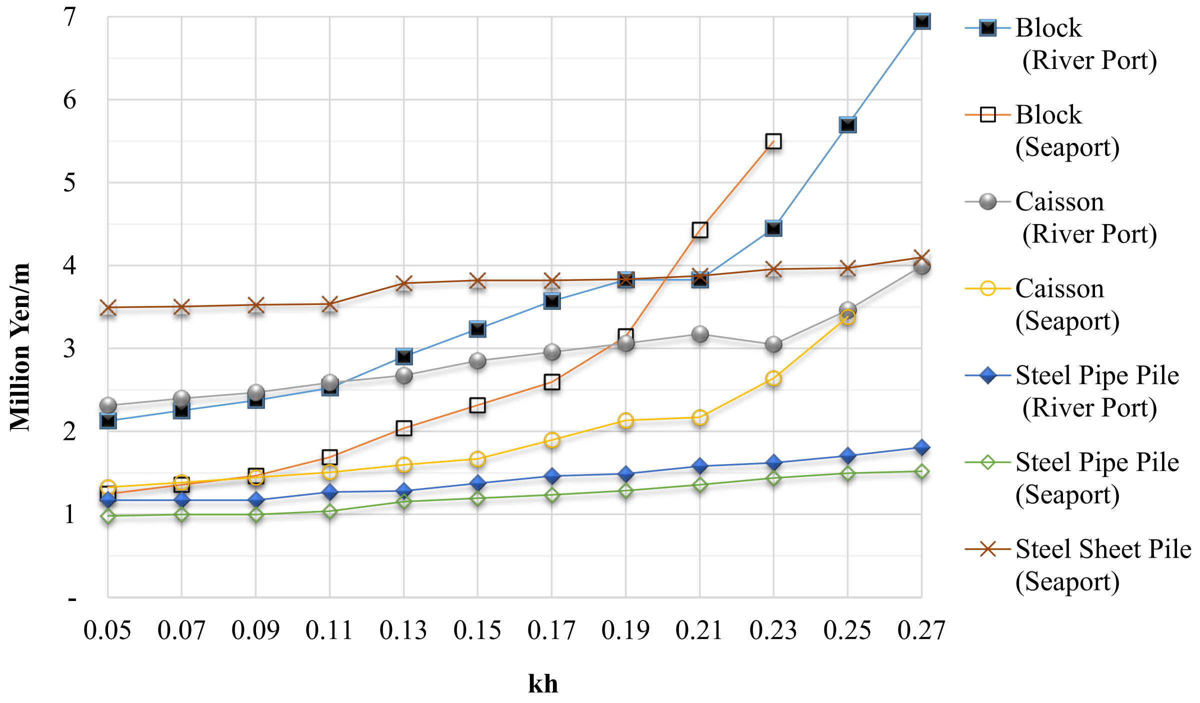


Figure 4-10 Construction cost of each structural type of quaywall

Considering the above 4 items, the results of cost calculation of each structural type of quaywall are shown the below **Figure 4-10**.

a) **Concrete Block**: the concrete block structure, which is the most preferable structure for quaywall at Shanoukville Port, has similar cost among other structures for seaport and lower than others for the case of river port. The cost of concrete block structure of both seaport and river port are drastically increased following the increasing value of kh. The cost of quaywall for river is higher than that of seaport, however, it turns to be lower than that of seaport for the case of kh = 0.21 – 0.23. This is because of the width of concrete blocks for river does not increased when kh varied from 0.19 to 0.21.

b) **Concrete Caisson**: The cost of concrete caisson structure is the most expensive among that of others at kh = 0.05, except that of steel sheet pile. The cost of concrete caisson structure of both seaport and river are slightly increased comparing to concrete block and its cost become lower than that of concrete block from kh = 0.9 as for seaport and from 0.13 as for river port. For the trend of cost in case of kh = 0.21 (as for seaport) and kh = 0.23 (as for river port) was dropped because of width of caisson become large so that the separated foundation for gantry crane is not required.

c) **Steel Pipe Pile**: the cost of steel pipe pile structure is the lowest comparing to others and it is slightly increased following the increasing value of kh. And cost of structure between seaport and river port are a little different of about 300,000 yen/m.

d) **Steel Sheet Pile**: the cost of steel sheet pile is the highest comparing others because the structure itself consists of continuous pipe wall and anchorage work and also the two pipe piles for supporting the rail of gantry crane. However, the cost is slightly increased following the increasing value of kh and become lower than that of concrete block for the case of kh > 0.21.

4.6 Constructability of each structural type of quaywall

In this section, we attempted to compare the constructability of each structural type of quaywall for Cambodia ports. Beside the applicability and cost of structure itself, constructability is the also a major constrain for the selection of suitable structural type of quaywall. The criteria to be considered in the comparison of the constructability are construction equipment, labour/engineer, and construction material supply. At this stage, there is no quantitative analysis of these criteria for the selection of suitable structure for Cambodian ports. Accordingly, this criteria will not be taken into account for the suggestion of suitable structural types of quaywall for Cambodian ports. Therefore, only some information related to these criteria are roughly described as the following sections.

4.6.1 Construction equipment

Construction equipment: in Cambodia only small scale of ship crane and crawler crane are available. From the hearing survey, the maximum capacity of crawler crane in Cambodia is only 100 tons. As shown in **Figure 4-11,** there are two ship cranes in Cambodia that are in service at Phnom Penh Port, however, the capacity is only applicable to the handling of cargo/container at the port.

For the medium ship crane, work vessel, and crawler crane are not available in Cambodia and these equipment always brought to Cambodia for temporary use for the major ODA projects such as bridge and port construction projects. As shown in **Figure 4-12**, the medium scale work vessel and crawler crane are being used for bridge construction by Chinese company.

For the case of port construction, the **Figure 4-13** show the construction of steel pipe pile quaywall for New Container Terminal Project of Phnom Penh Port which was completed in late 2012. Due to the lack of large scale work vessel, short pieces of concrete beams were constructed on land and transported to put and connect together on the pile heads.

Source: photo taken at Phnom Penh Port by author

Figure 4-11 Small scale ship crane and crawler crane

Source: sjg, Constructing Cambodia

Figure 4-12 Medium scale work vessels and crawler crane from other countries

Source: Phnom Penh Autonomous Port

Figure 4-13 Steel pipe pile quaywall construction at Phnom Penh Port (river port)

4.6.2 Skilled-labour/engineer:

Due to the lack of skilled-labour/engineer, the simple structure such as concrete caisson was always preferable for the construction of quaywall at Sihanoukville Port. Even though, the concrete caisson seem to be cheaper in material cost, but it requires large scale work vessel which

Source: Sihanoukville Autonomous Port

Figure 4-14 Concrete block fabrication (left), installation (center), and stone backfilling (right) at Sihanoukville Port requires much cost for mobilization and demobilization. The following **Figure 4-14** show the construction activities of concrete block type quaywall at Sihanoukville Port (seaport).

4.6.3 Access to construction material in local markets

In Cambodia the most of structures are reinforced concrete because most the materials are available in Cambodian markets. For steel materials, such as structural steel and steel pipe, are all imported from the other countries. Therefore, the reinforced concrete structures are always preferable in most of construction projects in Cambodia because the cost is reasonable.

4.7 Suitable structural types of quaywall

The suitable structural types of quaywall were evaluated considering the above three criteria, however, since the constructability was not sufficiently evaluated. Therefore, the suitable structural types of quaywall are suggested in accordance with the above three criteria: (1)applicability, (2)construction cost, and (3)constructability of each structural type as described in the previous sections.

(1) Applicability: in this criteria, the evaluation of suitable structural type is judged as "applicable" and "not applicable" the above **Table 4-9**.

(2) Construction Cost: in this criteria, the evaluation of suitable structural types is judged in three categories by considering the interval of the cost of quaywall structure. According to the above cost comparison as shown in the **Figure 4-10**, the cheapest cost of about 1.0 million Yen per 1 meter in length of concrete caisson quaywall was considered as the basic cost in evaluation.

- If cost of the structure is equal to or less than 2.0 million yen 1 m length of quaywall (Yen/m), it is considered as the "Lowest cost" structural type (lowest cost ≤ 2.0 million Yen/m).
- If the cost of structure is higher than 2.0 million Yen/m and less than 3.0 million Yen/m, it is considered as "moderate cost" structural type (2.0 million Yen/m <moderate cost < 3.0 million Yen/m).
- If the cost of structure is higher than 3.0 million yen/m, the structure is considered as "highest cost" structural type (highest cost ≥ 3.0 million Yen/m).

(3) Constructability: in this case three criteria are considered for the evaluation of the constructability such as construction equipment, skilled-labour/engineer, and access to construction material in the local markets. By considering these criteria, the simple structural type is considered as the most suitable (concrete block). For concrete caisson, it required large scale ship crane for installation of caisson. Moreover, other heavy equipment may be also required such as floating dock, and slipway, etc. And, the mobilization and demobilization of these heavy equipment is too costly. For the case of steel pipe pile and steel sheet pile, even though some medium scale pile driving machines are available from neighboring countries, but the materials such pile and related materials are not available in Cambodia and they may require high cost for transporting them from other countries.

By considering the above three evaluation criteria, the suitability of each structural type of quaywall for Cambodian river port and seaport and Japanese seaport were suggested as shown in the following **Table 4-11**. The results shown in this table are limited to the conditions and assumptions in the case study of Sihanoukville Port (largest seaport) and Phnom Penh Port (largest river port).

Since the design conditions and parameters used in the design may vary from site to site, these results may not applicable other cases. If these results are subjected to be widely applied to other cases in Cambodia, more case studies should be carried out for other ports in Cambodia with different design conditions and parameters, e.g., vessel size, scale of structure, subsoil condition, etc. Moreover, more types of structures should be also evaluated for the selection of suitable structure types.

Table 4-11 Suitable structural types for facilities in Cambodia and Japan

	Concrete Block	Concrete Caisson	Steel Pipe Pile	Steel Sheet Pile
River Port (Cambodia)	C	B (A in future)	B	-
Seaport (Cambodia)	B	B (A in future)	B	C
Seaport (Japan)	C	A (for medium earthquake region) C (for strong earthquake region)	B	C

A: Most suitable; B: Suitable; C: Not suitable

***Note**: the results shown in this table are limited to the conditions and assumptions in this case study, particularly, the design was considered only maximum size of vessel. Thus, these results may not be applicable to other general cases.*

5 Conclusion

The conclusions and considerations from this study are shown as follows:

(1) The differences of three major disasters: earthquake, typhoon, and flood between Japan and Cambodia were evaluated and the considerations of the respective disaster are summarized as follows:

- ***Earthquake****:* Horizontal seismic coefficient (kh) of 0.05 or lower was suggested for port facilities design in Cambodia, which is much smaller than that in Japan where kh ranged from 0.05 to 0.27.
- ***Typhoon***: with a return period of 50 years, three parameters were estimated from typhoons landed in Cambodia between 1951 and 2013 considering the effect of local fetch of 50 km: maximum typhoon wind speed, U = 25.7 m/s (i.e., tropical storm); significant wave height, $H_{1/3}$ = 3.9 m; and significant wave period, $T_{1/3}$ = 7.3 s at Sihanoukville port. These parameters are suggested the design for the design of Cambodian ports against typhoon condition, which are smaller than that in Japan.
- ***Flood***: with a return period of 50 years, maximum flood water level of 11.65 m which is about 9.0 m different from annual average minimum water level in dry season. These flood and draught are characteristic events in Cambodia's rivers, and they should be considered in Cambodian technical standards.

(2) By applying the Japanese Technical Standards to Cambodian conditions, the suitable structural types for port facility (quaywall) were evaluated considering three criteria: stability against natural disasters, construction cost, and constructability of each structural type. However, constructability is not quantitatively evaluated, therefore, it was roughly considered in the selection of suitable structural type of quaywall. The suitability of structural types of quaywall was evaluated among four structural types, namely, concrete block (CB), concrete caisson (CC), Steel pipe pile (SPP), and steel sheet pile (SSP). As for ports in Cambodia, CC and SPP are "suitable", SSP is "not suitable" for both seaport and river port. CB is "suitable" for seaport, but "not suitable" for river port because of large water level fluctuation.

(3) In order to develop official standards for Cambodia, Japanese Technical Standards should be modified with reference to the above conditions of natural disasters, particularly, small kh in Cambodia. In spite of the limitations and assumptions in this study, we clarified some suggestions as follows:

- The effects from earthquake and typhoon should not considered in the design of port facilities in Cambodia.
- The effects from flood should be considered for the design of river ports, but not for seaports.

(4) For future work, other cost (e.g., labour, equipment, and maintenance) should be considered for more accurate cost estimation of each structural type of quaywall. Furthermore, the constructability shall be quantitatively evaluated considering, e.g., skilled-labour/engineer, equipment, construction materials, etc.

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Appendix

1. Current situations of waterborne transport in Cambodia

1.1. Organizations related to port management and operation

1.1.1. Gate committee

The following contents are described based on OCDI (20011). Sub-Decree No.64 on "The Designation and Management of the Control Offices at the International Gates, the International Border Gates, the Bilateral Border Gates, the Gates at the Border Areas and the Seaport Gates across the Kingdom of Cambodia" was stipulated on 9 July 2001. The aim of this sub decree is to ensure security, stability, social law and order and protect people's well-being and State's revenues (Article 1).

The International Gates are composed of Phnom Penh International Airport, Phnom Penh International Port, Sihanouk Ville International Seaport and Airport, and Seam Reap Airport.

The control office of the International Port Gate in Phnom Penh is composed of (Article 13):

- PP International Port of the Ministry of Public Works and Transport (port authority)
- Department of Foreigners of the Ministry of Interior (immigration and safeguard)
- Customs and Excise of the Ministry of Economy and Finance (for duties and taxes)
- CAMCONTROL of the Ministry of Commerce (Import-Export Inspection and Fraud Repression)
- KAMSAB of the Ministry of Public Works and Transport (the government-owned shipping agent for marine cargo)

The control office of the Sihanouk Ville International Port consists of:

- Sihanouk Ville International Port of the Ministry of Public Works and Transport (port authority)
- Department of Foreigners of the Ministry of Interior (immigration and safeguard)
- Customs and Excise of the Ministry of Economy and Finance (for duties and taxes)
- CAMCONTROL of the Ministry of Commerce (Import-Export Inspection and Fraud Repression)
- KAMSAB of the Ministry of Public Works and Transport (the government-owned shipping agent for marine cargo)

1.1.2. Seaport gates

Besides two international gate ports, other seaport gates are designated as follows (Article 11):

- Kampot Province: Koh Ses, Trapaing Lapoa and the Provincial town
- Kep town: Kep town
- Sihanouk Ville: Tomnop Rolok Sar, and Steng Hav
- Koh Kong Province: Bak Khlorng, Thmor Sar, Sre Ambel and Koh Sdech

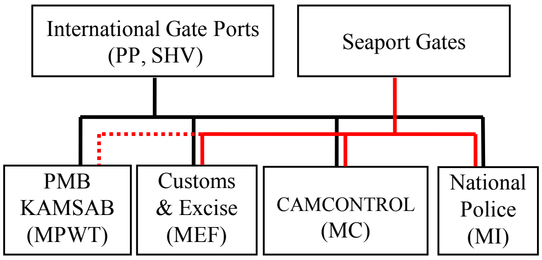
Control office of these seaport gates is composed of (Article 17):

- Province or Town
- Provincial and Town Police
- Custom and Excise of the Ministry of Economy and Finance
- CAMCONTROL of the Ministry of Commerce

Since this Sub Decree was promulgated in 2001, private ports, Oknha Mong Port and New Sre Ambel Port, are not stipulated in Article 11. However, KAMSAB assigned officials at these ports and joined their gate committees as de facto member. Revision of Dub Decree No.64 will be necessary to cope with the recent evolution of privately managed seaports.

1.1.3. Role of MPWT and MEF on port management

Whilst autonomous ports are managed by state owned enterprises, the government intervenes in ship entry permission, collection of port dues and taxes, cargo handling tariff, and shipping lines/agents business certificate, and others from the view point of national security, welfare, economic stability, navigation safety, fare competition and the like.



PMB: Port Management Body

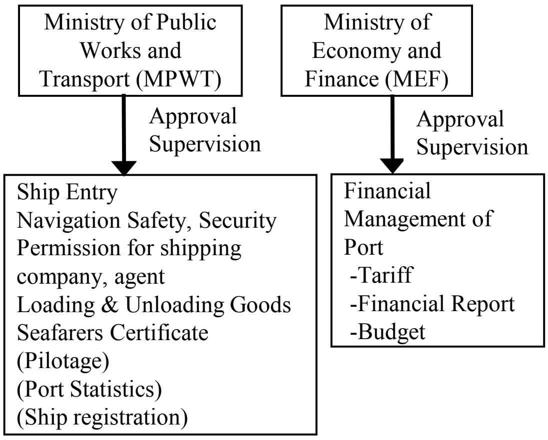
Source: OCDI, 2011

Figure 1-1 Gate committee

KAMSAB: Kampuchea shipping agency and brokers
MPWT: Ministry of Public Work and Transport
MEF: Ministry of Economy and Finance
CAMCONTROL: Import-Export Inspection and Fraud Repression Directorate General
MC: Ministry of Commerce
MI: Ministry of Interior
CMs: Council of Ministers (also called Cabinet of Cambodia)

MPWT and MEF play major role in supervising port management and operation of autonomous ports and provincial ports as shown in Box-2. However, no effective supervision is taken place at privately managed ports. Financial supervision/approval may not be so important for private ports. However, ship entry permission by MPWT is particularly important for the sovereignty of the country and port security.

Since the draft of Ministry Notification on the Entry of Ship Navigating Internationally at the Port of the Kingdom of Cambodia has drafted in 2006, this notification shall be issued as soon as possible. It may be appropriate if this notification is promulgated as a sub decree. Responsible ministry shall be MPWT and the Ministry in charge of coast guard.



Source: OCDI, 2011

Figure 1-2 Functions of MPWT and MEF on port management

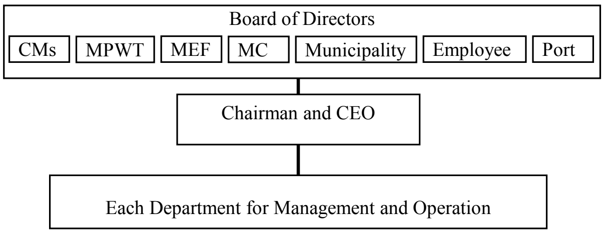
1.1.4. Organization of port management body (PMB)

(1) Autonomous Ports

Port of Phnom Penh has had a commercial facility since the beginning of 20th century and the Port of Sihanoukville was developed after the independence of Cambodia in 1953. After a long period of civil war, import was resumed from the beginning of 1980s. Rehabilitation of ports started in the mid-1980s.

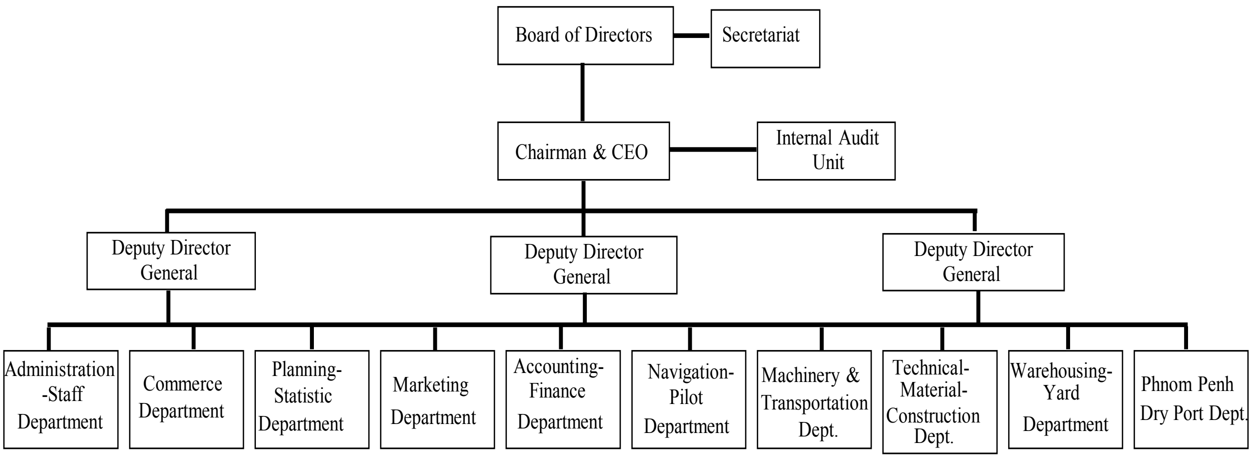
The Law on the Establishment of the Ministry of Public Works and Transport was promulgated in 1996, and Sub Decree No.14 on the Organization and Functioning of the Ministry of Public Works and Transport was promulgated in March 1998, which determined the Ministry shall be responsible for port administration. Following the Sub Decree on organization of MPWT, Sub Decrees on the establishment of the Sihanoukville autonomous port and Phnom Penh autonomous port were promulgated in July 1998.

Ports of Sihanoukville and Phnom Penh were transformed into autonomous bodies based on Sub Decrees No.50 and No.51 on 17 July 1998 entitled "Establishment of the Sihanoukville Autonomous Port" and "Establishment of the Phnom Penh Autonomous Port" respectively. Both ports have the board of directors and are able to manage by their own capacity, however, they are under the direction of MPWT in terms of technical matters and MEF in terms of financial matters.



Source: OCDI, 2011

Figure 1-4 Autonomous port administration

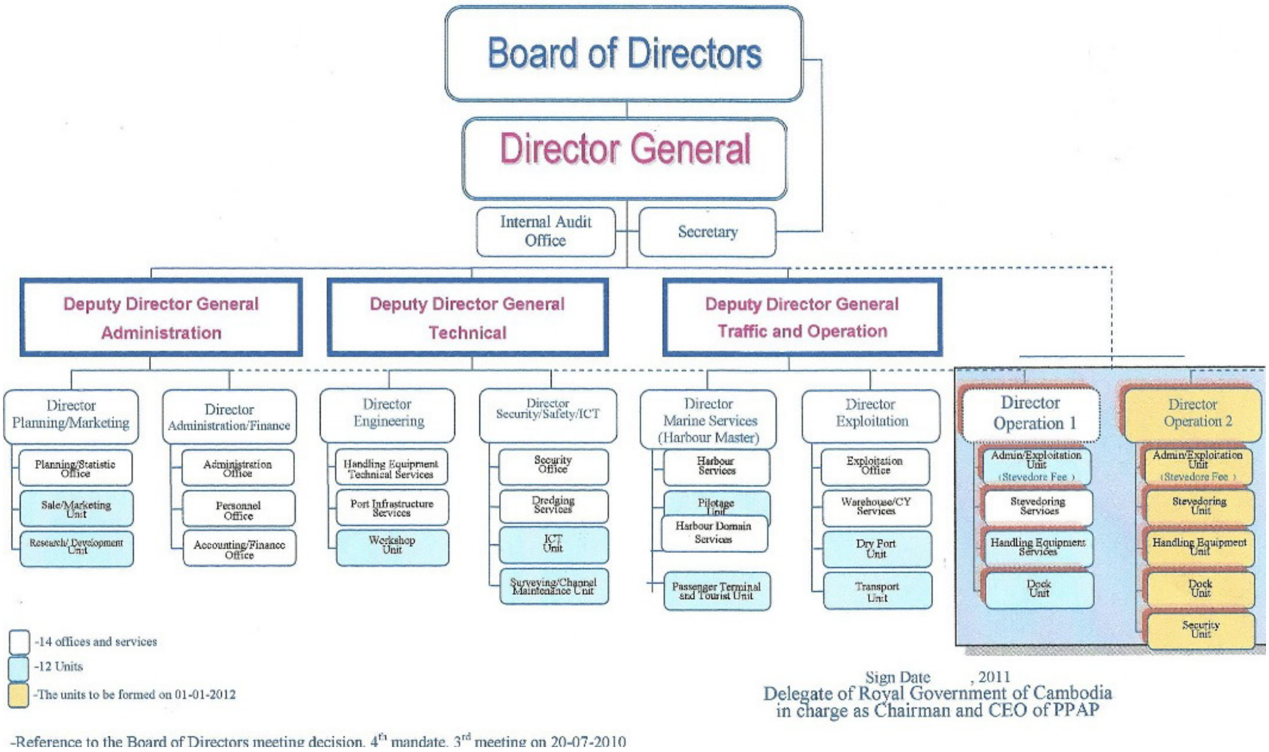


Source: OCDI, 2011

Figure 1-3 Organizational structure of PAS

Board of Directors of autonomous port is composed of representatives from following organizations:

- Ministry of Public Works and Transport (MPWT)
- Council of Ministers (CMs)
- Ministry of Economy and Finance (MEF)
- Sihanoukville/Phnom Penh Authority (SA/PP) (municipal/local government)
- Ministry of Commerce (MC)
- PAS/PPAP Employee
- Director General of PAS/PPAP



Source: OCDI, 2011

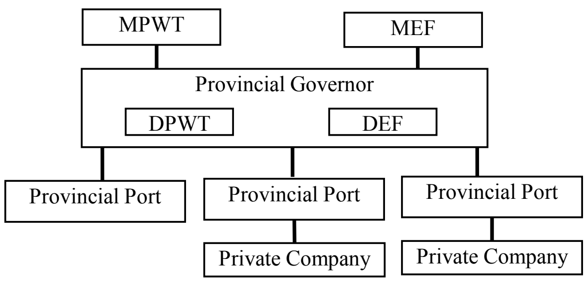
Figure 1-5 Organizational structure of PPAP

Note: The Port Infrastructure Services under Engineering Section and Technical Department is in charge of port construction. Since the port development project have been supported by foreign countries, therefore, port design and construction are done by donor countries. However, the quality of construction is controlled/checked by the above Department.

(2) Provincial Ports

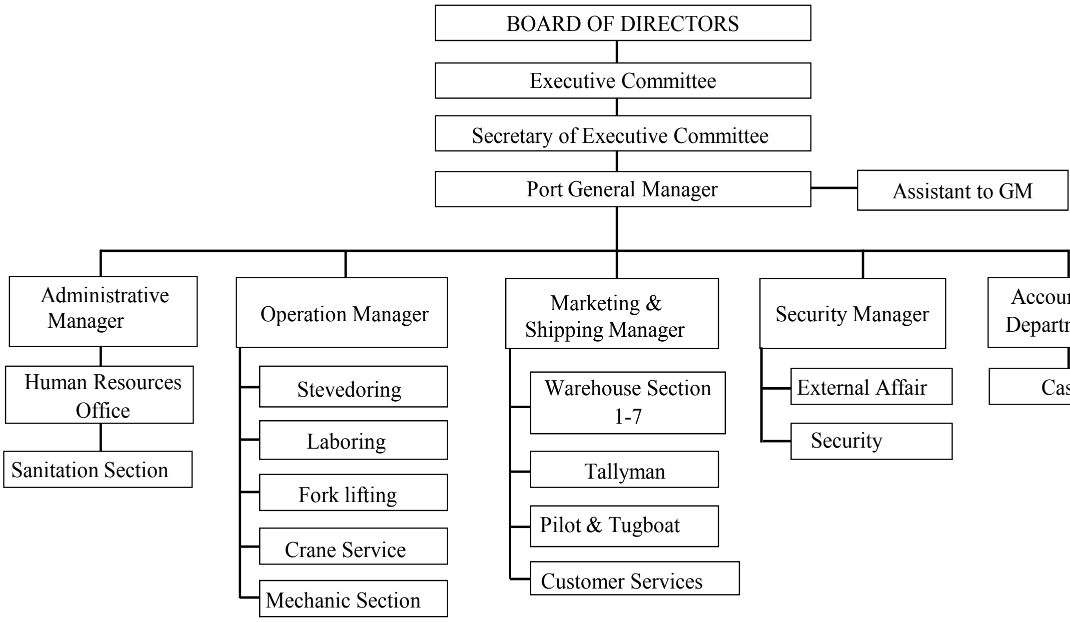
Provincial ports are maintained by the Department of Public Works and Transport (DPWT). However, their port dues are proposed by Department of Economy and Finance (DEF) of provincial government and become effective after the approval of MEF. Collection of port dues is commissioned to private company selected by competitive bids. In this regard, port management body of provincial port is DPWT and DEF. Both organizations are supervised by provincial governor and each ministry.

Port management body shall be established by DPWT and DEF jointly and manage the development of new facilities, rehabilitation of present facilities, and participation of private companies in port activities.



Source: OCDI, 2011

Figure 1-6 Provincial port management



Source: OCDI, 2011

Figure 1-7 Private port organization (Oknha Mong Port)

(3) Private Ports

Organization of Oknha Mong Port is shown in **Figure 1-7** (refer to section **Oknha Mong Port (SP3))** for the details of this port). Both organizations are very similar in terms of operation, stevedoring, marketing, accounting and pilot services. Differences are seen in planning and statistics, construction, and dry port department.

While Customs and Excise, CAMCONTROL and Immigration Police have offices at two private ports for the purpose of trade control, port management is implemented by private port company. Functions of MPWT and MEF on port management shown in Box-2 are not implemented at private ports. It is necessary to stipulate necessary procedures for ship entry, navigation safety, port security, permission for shipping companies and agents, loading & unloading goods, seafarers certificate inspection, pilotage, port statistics, ship registration, and other necessary provisions on port activities.

1.2 Maritime and Seaports

1.2.1. Present state of seaports

Among the seaports in Cambodia, Sihanoukville Port is the major port that handles international containers. It is under the MPWT and MEF, but is autonomously-managed ports, which is officially called Port Autonomous of Sihanoukville (PAS). The port construction was completed in 1960 by French assistance. Sihanoukville Port locates in newly established Sihanoukville province, while Cambodia's other seaports locate mainly in Koh Kong and Kampot provinces.

1.2.2. Sihanoukville Port

Sihanoukville Autonomous Port (PAS) is the only deep sea port of the kindom of Cambodia which is located in Preah Sihanouk province in the southwest of the country.

The port construction was completed in 1960 by French assistance. Beside Sihanoukville Port locates in newly established Sihanoukville province, Cambodia other seaports locate mainly in Koh Kong and Kampot provinces.

This port has great potential, sufficient infrastructures related to the logistics and distribution affairs, together with naturally good advantages mountain ranges and many islands as protective barriers against natural disasters, and has never suffered from tidal storms, earthquake, tsunami, flooding, and landslide.

In the move forwards the effective logistics and distribution center, PAS is linked by the multi-modal transport systems which consist of lorries, train, ship, and plane to serving the needs of internal and external customers.

(1) Transportation Networks

As shown in **Figure 1-8**, among the total container import/export of Cambodia, the shared amount through the major routes are as follows (hearing survey with JICA Expert in Cambodia):

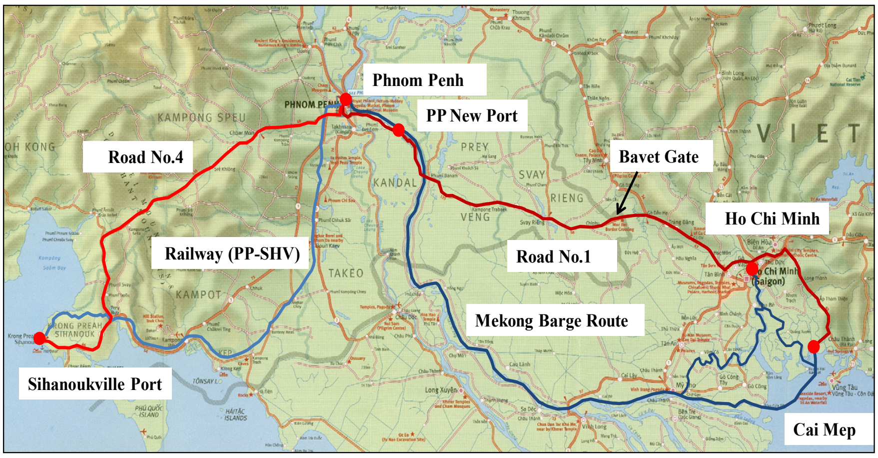
- 50% Seaport: Sihanoukville Port (Phnom Penh – Sihanoukville Port via National Raod No. 4.
- 35% River port: between Phnom Penh and Ho Chi Minh and Cai Mep (Vietnam) port

via Inland Water Route (Mekong Barge Route).
- 15%: Through border (Phnom Penh – Ho Chi Minh via National Road No. 1)

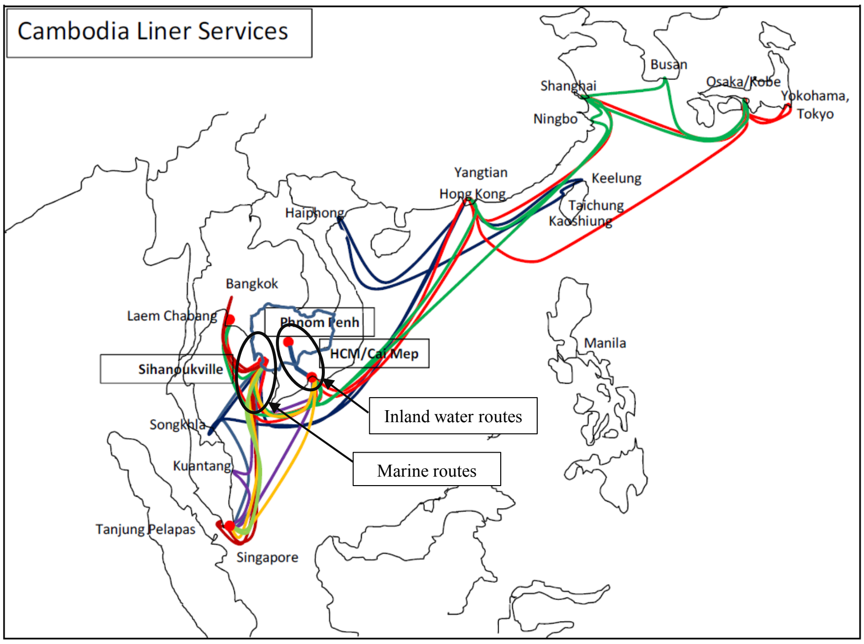
(a) Local Transportation Networks (Figure 1-8)
- National Road No. 4 : 226 km
National Road No. 3 : 224 km

(b) International Transport Networks around Cambodia (Figure 1-9)

International liner services are calling at Sihanoukville Port, but services are limited to ASEAN and East Asian ports as shown in **Figure 1-9**. Directly linked ports are Singapore, Tanjung Pelapas, Hong Kong, Ho Chi Minh,



Source: PAS
Figure 1-8 Local transport networks in Cambodia



Source: Survey Team

Source: JICA, 2013
Figure 1-9 Liner service loops from PAS (as of 2012)

- Railroad : 264 km, and
- By Kang Keng Airport of Preah Sihanouk province connected with Phnom Penh International Airport, Siem Reap Airport, and other countries.

Cai Mep, Laem Chabang, Songkhla, Kuantang, Kobe, Osaka, Tokyo, Yokohama, Shanghai, Busan, Ningbo, and Yangtian. Singapore Port plays the role of a hub port which connects Sihanoukville Port to major trunk services to Europe and North America.

Phnom Penh Port is a river port and container service is limited to Ho Chi Minh and Cai Mep. Vessels deployed are barge type container vessels with a capacity of 120 TEUs or less. All containers are transshipped at HCM or Cai Mep Port and carried to final destinations. Due to the availability of truck liner services from Cai Mep Port, export containers from Phnom Penh Port are destined for North America and East Asian countries. Containers to Europe are mainly carried through Sihanoukville Port.

Shipping companies serving at Phnom Penh Port are Sovereign, GEMADEPT, and New Port Cypress (Ben Line Agencies) as shown in **Table 1-1**. Other shipping companies suspended services to Phnom Penh Port as of October 2012. GEMADEPT has the largest share of 66.7% followed by Sovereign of 22.1% and New Port Cypress of 11.3%. Liner shipping loops from/to Sihanoukville port are shown in **Figure 1-9** and their details are as shown in **Table 1-1** below.

Table 1-1 Ship Call at Sihanoukville Port (as of 2014)

Source: PAS

Lines	Calling Schedules	Frequency	Rotation Ports
RCL (4 calls/week)	1. Wed 08 : 00 – Wed 23 : 00 2. Wed 08 : 00 – Thu 16 : 00 3. Thu 14 : 00 – Fri 22 : 00 4. Fri 2 0 : 00 – Sat 23 : 59	1 call/week 1 call/week 1 call/week 1 call/week	1. NBO-SHV-BKK-LZP-MAT-SGH-NBO 2. SIN-SHV-SGZ-SIN 3. HKG-SHV-SGZ-HKG-(HPH-TXG-KEL) 4. KUN-SHV-SGZ-SIN-KUN
MAERSK (2 calls/week)	1. Tue 15 : 00 – Wed 07 : 00 2. Fri 22 : 00 – Sun 00 : 01	1 call/ week 1 call/ week	1- SGN-SHV-LZP-TPP-SIN-BTG-MNL-KAO-YAT-HKG-HCM 2. SIN-SHV-TPP-SIN
SITC (BEN LINE) (2 calls/week)	1. Sun 09 : 00 – 23 : 00 2. Tue 07 : 00 – 17 : 00	1 call/week 1 call/week	1. HCM-SHV-BKK-LZP-HCM-NSA-NBO- SGH-OSA-KOB-BUS-SGH-HKG-HCM 2. HCM-SHV-BKK-LZP-HPH-FCH-SHK-XMN-INC-TAO-SGH-HKG-SHK-HCM
EML /ACL (1 call/week)	Sat 06 : 00 – Sun 08 : 00	1 call/week	SGZ-SHV-SIN-SGZ
APL (1 call/week)	Fri 08 : 00 – Sun 06 : 00	1 call/week	SIN-SHV-SIN
NAM YUEN YONG (1 call/2weeks)	Mon 08 : 00 – 13 : 00	1 call/2 weeks (~3 Calls / month)	BKK-SHV-BKK- (LZP)
Total	11/ Calls / week		

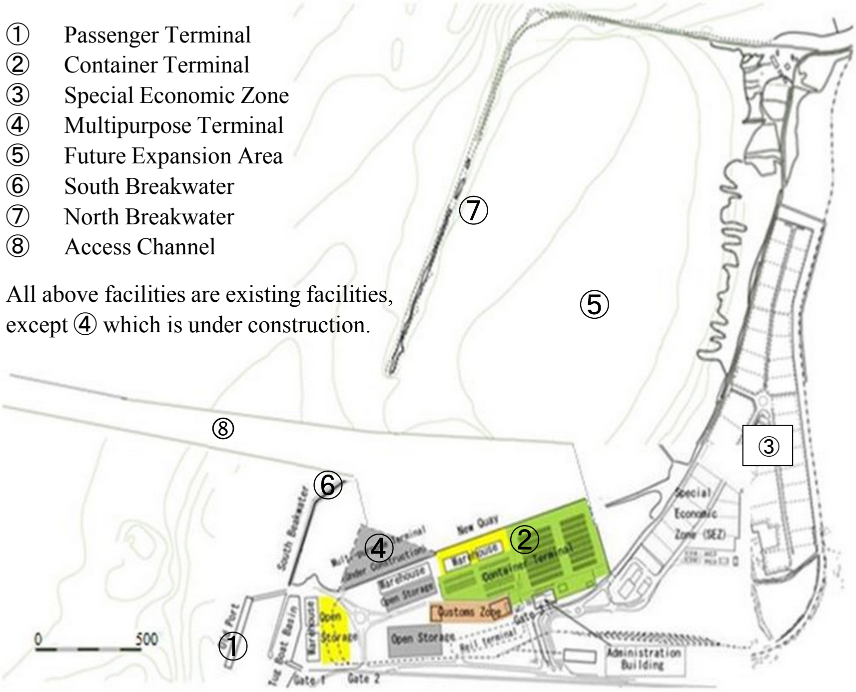
Remark:

BKK	:	BangKok, Thailand	**INC**	:	Inchon, Korea	**NSA**	:	Nansha, China	**SGZ**	:	Songkla, Thailand
BUS	:	Busan, South Korea	**KOB**	:	Kobe, Japan	**NBO**	:	Ningbo,China	**SHK**	:	Shekou, China
BTG	:	Bantagas, Philippine	**KUN**	:	Kuantan, Malaysia	**OSA**	:	Osaka, Japan	**TPP**	:	Tanjung Pelepas, Malaysia
FCH	:	Fangcheng, China	**KEL**	:	Keelung, Taiwan	**PEN**	:	Penang, Malaysia	**TXG**	:	Taichung,Taiwan
HKG	:	HongKong	**LZP**	:	LaemChabang,Thailand	**SHV**	:	Sihanoukville Port, Cambodia	**TAO**	:	Quingdao, China
HPH	:	Hai Phong, Vietnam	**MNL**	:	Manila, Philippine	**SGH**	:	Shanghai, China	**XMN**	:	Xiamen, China
HCM	:	Ho Chi Minh, Vietnam	**MAT**	:	Map Ta Phut, Thailand	**SIN**	:	Singapore	**YAT**	:	Yantian, China

According to the Brochure of Sihanoukville Port published in 2014, there are 6 companies have their ships called regularly at Sihanoukville Port, namely RCL, MAERSK, SITC, EML, APL, and NAM YUEN YONG (see **Table 1-1**).

The Port of Sihanoukville, situates in mouth of the Bay of Kampong Som – Sihanoukville province, is the principal and only deep seaport of the Kingdom of Cambodia. Sihanoukville's natural advantages include deep inshore and a degree of natural protection from storms.

The present traffic of Sihanoukville Port, in its present condition, is estimated at about 2.4 million tons per year, including Petrol-Oil-Lubricant (POL), which has separate facilities. The port can accommodate 10,000 DWT cargo ships and 20,000 DWT class container ships. To enhance the economic development, PAS, with financial support by Japan, has established Special Economic Zone (SEZ).



Source: MPWT, 2012 (modified)

Figure 1-10 Port Layout

Table 1-2 Major infrastructure of PAS

Prepared based on the data from PAS and MPWT (2012)

Channel	Berth						
	Zone	Name		Structure	Length(m)	Depth(m)	Year
[South Channel] Length: 5.5km	①	Old Jetty	Outer	Jetty	290	-9.0	1960
			Inner	Jetty	290	-8.0	
Depth: -8.5m	②	New wharfs		Concrete block	350	-8.5	1970
Width: 80-100m		Container berth		Concrete block	400	-10.0	2007
	④	Multi-purpose terminal	Multi-purpose wharf	Concrete block	260	-13.5	2014
			Oil supply berth	Concrete block	200	-7.5	
[North Channel]	Another location	(Private Facilities)					
Length: 1km		Sokimex		Jetty	-	-10.0	-
Depth:-10m		Tela		Pontoon	-	-6.5	-
Width:150-200m		-		Stone wharf	-	-4.2	-

(3) Lift on-off equipment

Terminal	Size(m^2)	Capacity	Quantity
New Terminal	103,000	8,400 TEUs	01
Empty Container yard	46,000	3,000 TEUs	01
Reefer Container		54 boxes	9 sockets
Container Freight Station	6,000	12,000t	01(Warehouse Nº4)

(4) Storage facility

Terminal storage facilities

Terminal	Size(m^2)	Capacity	Quantity
New Terminal	103,000	8,400 TEUs	01
Empty Container yard	46,000	3,000 TEUs	01
Reefer Container		54 boxes	9 sockets
Container Freight Station	6,000	12,000t	01(Warehouse Nº4)

General cargo storage facilities

Terminal	Size	Capacity	Quantity
Rail lane	500 m		02
Rail Container Terminal	35000m^2	232 TEUs/1slot	01unit

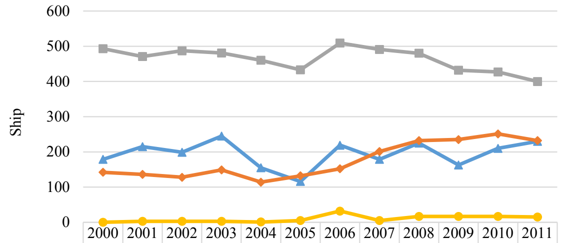
Railway cargo storage facilities

Terminal	Size	Capacity	Quantity
Rail lane	500 m		02
Rail Container Terminal	35000m^2	232 TEUs/1slot	01unit

(4). Port's Statistics

(a) Ship call

General Cargo (GC) ship, Oil tanker (Tanker) and Containerized Cargo (CC) ship account more than 98% ship call at Sihanoukville Port. Passenger ship account less than 2% of total ship call. All ship calls are increased, but the GG ship. There are two reasons for this decrease: the competiveness from other private ports (e.g., Oknha Mong Port) which are newly developed with relatively closer distance to Phnom Penh City and the number of ships used to transport cement from Thailand was decrease because cement cold be produced in Cambodia.



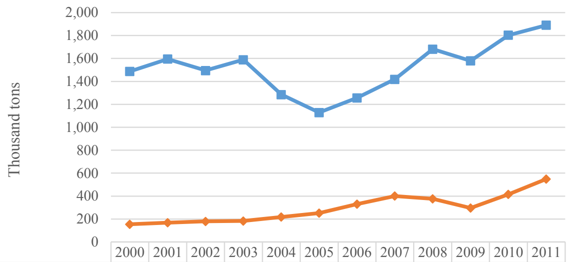
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CC ship	179	215	199	245	155	116	219	179	225	163	210	230
Tanker	142	136	128	149	114	132	152	201	232	235	251	232
Container	493	471	487	481	460	433	509	491	480	432	427	400
Passenger	0	3	3	3	1	5	32	5	17	17	17	15

Source: MPWT, 2012

Figure 1-11 Number of ship call at Sihanoukville Port

(b) Cargo throughput

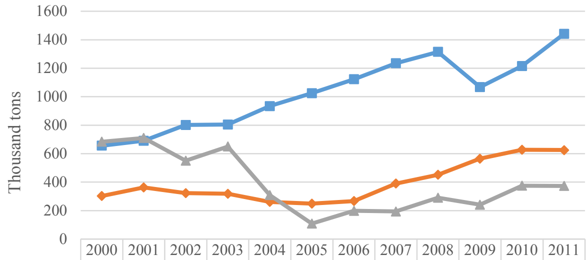
Export increases more than 3 folds over the last 11 years and within the same period of time Import increases by only less than 1 fold. However import volume always remains higher compare to export volume.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Import cargo	1,487	1,595	1,495	1,589	1,285	1,129	1,256	1,418	1,681	1,579	1,803	1,890
Export cargo	155	168	180	183	218	252	331	401	377	296	415	549

Source: MPWT, 2012

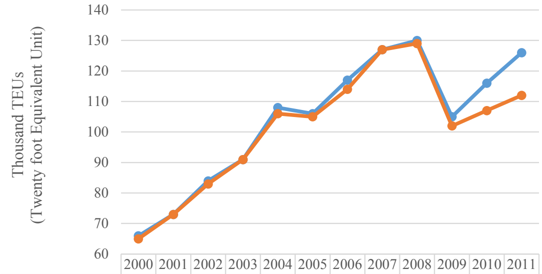
Figure 1-12 Import & export Trends of all cargos at Sihanoukville Port



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
CC	656	691	802	805	934	1,024	1,123	1,235	1,315	1,068	1,215	1,442
Fuel	302	363	323	318	261	249	267	390	452	565	627	625
GC	684	710	550	650	308	108	198	194	291	241	375	373

Source: MPWT, 2012

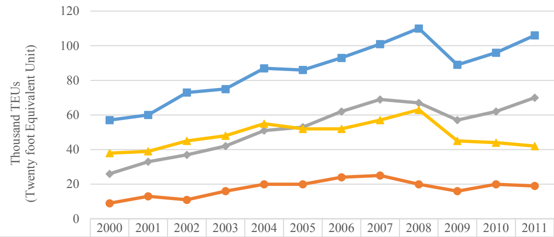
Figure 1-13 Trends of all cargos at Sihanoukville Port



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Import cargo	66	73	84	91	108	106	117	127	130	105	116	126
Export cargo	65	73	83	91	106	105	114	127	129	102	107	112

Source: MPWT, 2012 (modified)

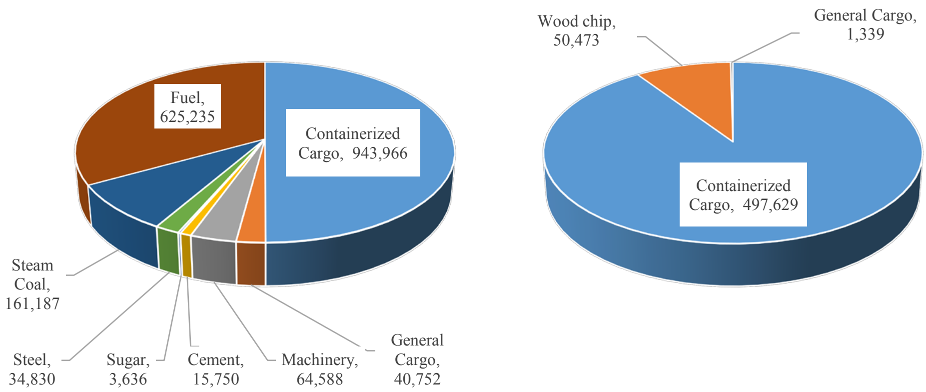
Figure 1-14 Import & export trends of containerized cargo at Sihanoukville Port



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Import Laden	57	60	73	75	87	86	93	101	110	89	96	106
Import Empty	9	13	11	16	20	20	24	25	20	16	20	19
Export Laden	26	33	37	42	51	53	62	69	67	57	62	70
Export Empty	38	39	45	48	55	52	52	57	63	45	44	42

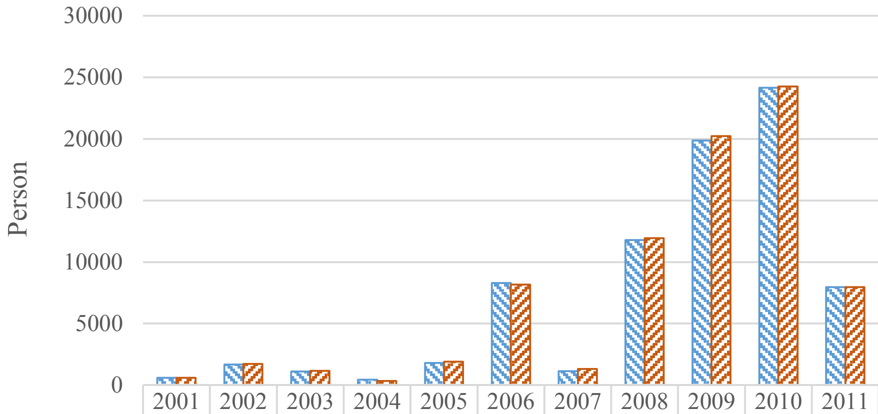
Source: MPWT, 2012

Figure 1-15 Trends of ratio of empty and laden containers at Sihanoukville Port



Source: MPWT, 2012

Figure 1-16 Composition of exported (left) and imported (right) items at Sihanoukville Port (tons)



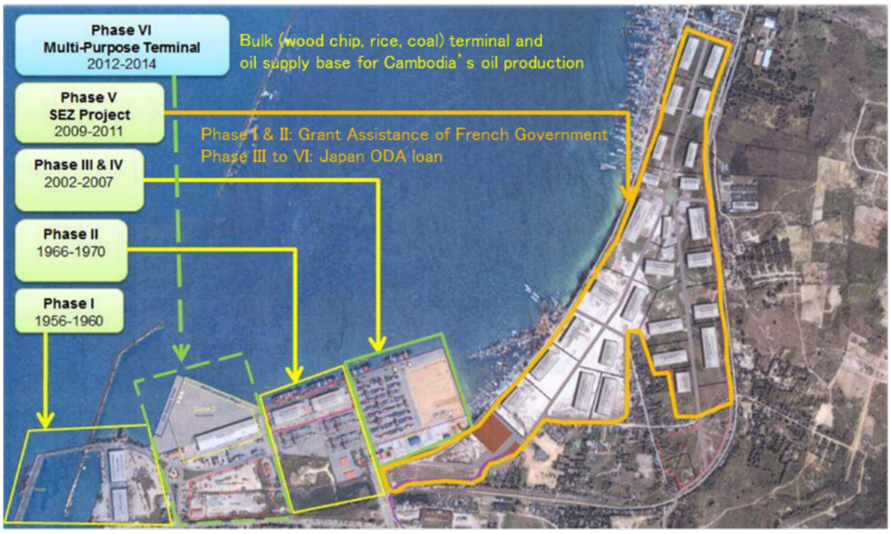
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Pass. Arri.	588	1,673	1,113	447	1,797	8,303	1,141	11,788	19,853	24,142	7,964
Pass. Dept.	589	1,734	1,169	354	1,909	8,162	1,318	11,926	20,217	24,261	7,958

Source: MPWT, 2012

Figure 1-17 Number of passengers at Sihanoukville Port

(6) Port Development Phase and Plan

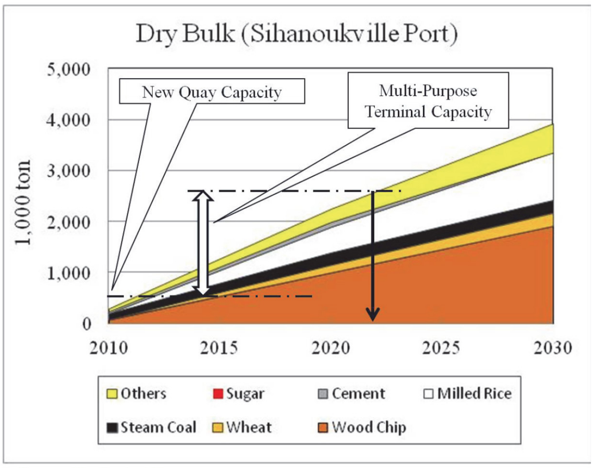
The Sihanoukville port was first built in 1956-1960 under the grant assistance of French government and it has been continuously improved and developed years by years. From the development phase III to phase VI, Sihanoukville port including SEZ project have been supported by Japan ODA loan. The development phase VI of construction of Multi-purpose Terminal is now under construction.



Source: MPWT, 2012 (modified)

Figure 1-18 Development phase of PAS with corresponding assistance

(1) Multipurpose Terminal Development Project (2014 – 2017)



Prepared by Project Team

Source: JICA, 2012

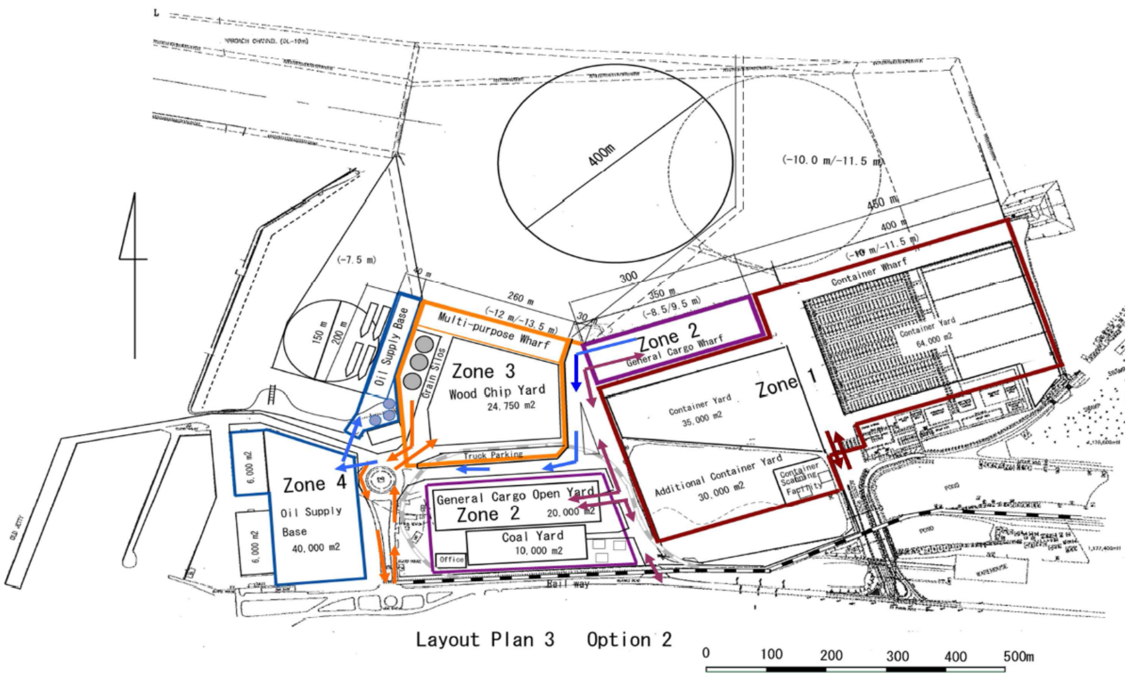
Figure 1-19 Dry bulk and break bulk cargo volume and the capacity of the new quay and multipurpose terminal

To ensure serviceability and profitability in the business world, future development plan of PAS depends directly on export and import demands. Based on the forecasted of dry bulk cargo volume in **Figure 1-19** below (source: JICA Report), the development of Multipurpose Terminal Project is required. The usage of this new terminal area are described as follows:

- To support the government's target of 1 million ton of rice to be exported by 2015. This demand requires expansion and construction of the storage facilities, terminal and links with railway (zone 1 & zone 2). Referring to the statistic data of rice export via Sihanoukville Port, rice export has increased sharply from 50,864 t in 2010 to 318,101 t in 2013 (data provided by Sihanoukville Port).

- To support the export of forest-related product. This demand requires the refurbishment of wood chip yard where it also could be used as multi-purpose terminal (zone 3).

- To support current oil import and also prepare ground for future oil export (zone 4). Excluding overlapped area with neighbor countries, there are 6 offshore oil blocks (from A to F blocks). In 2005, Chevron announced oil discovery in Block A (6,278 km2) and Commercial discovery was announced in 2010. Oil exploitation is expected to taking place in the very near future.



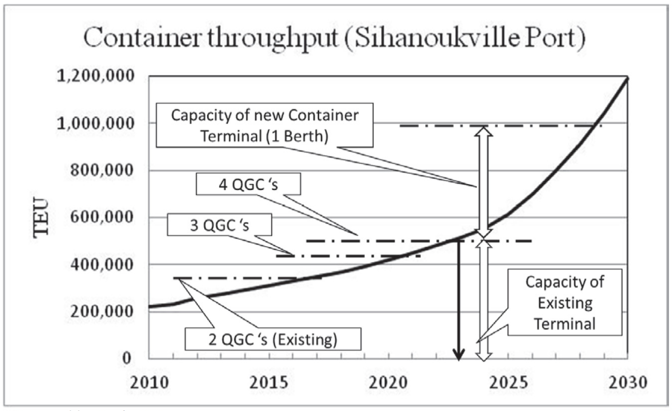
Source: MPWT, 2012

Figure 1-20 Multipurpose terminal development project

(2) Development Plan up to 2030

① Construction of New Container Terminal (2018-2028)

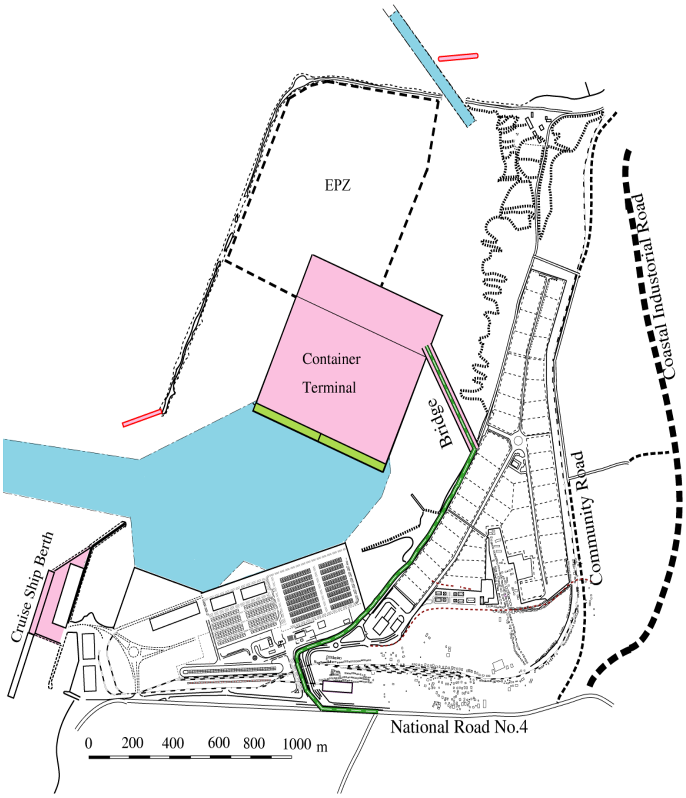
In order to fulfil the increasing volume of port container throughput demand (as shown in **Figure 1-21** below), the development of new container terminal is required.



Prepared by Project Team

Source: JICA, 2012

Figure 1-21 Container cargo volume and capacity of container terminal



Source: PAS

Figure 1-22 Future development plan up to 2030 (container terminal and cruise ship terminal)

Based on the data provided by Sihanoukville Port, the new container terminal development project are shown as follow:

a). New Container Terminal: (Length: 350m + 350m; Depth: -14m)
- Container Yard: 36ha;
- Open Yard: 4ha
- Administration Building,
- Terminal Gate, Power Station,
- Port Facilities etc.

b). Procurement of Handling Equipment:
- Quayside Gantry Crane 30.5t (Post Panamax): 6 Units
- Rubber Mounted Gantry Crane (6 rows, 4+1): 18 Units
- Top Lifter/Reach Stacker (7.5tons): 9 Units
- Tractor & Chassis (40' container): 26 Units
- Light Tower: 18 Units

② Construction of Cruise Ship Terminal (2022 – 2025)
- Cruise ship Terminal Berth: (Length: 400m, Depth: -9.5, Width: 30m)
- Reclamation Works: 690,000m³
- Dredging Works: 21,000m³
- Yard Pavement & Drainage Systems: 53,000m²
- Mechanical & Electrical Systems: 1 LS

1.2.3. Other Seaports *(refer to the Figure 1-23 for the locations of these port, source MPWT Report 2012)*

Koh Kong Port (SP1) SP1 was managed by provincial Department of Public Works and Transport (DPWT). It was built in 1992, at Lat: 11d32'859"N / Long: 102d56'426"E; size: 30m x 10m. Accessibility to this port could be made by dusty dirt road. Water level at low and high tide is between 3m and 5m. Water level could support up to 300-ton vessel. Goods brought to this port are mostly cement and construction material, which are estimated around 4,000 -7,000 tons per month. There are between 2-3 ship calls per month at SP1.

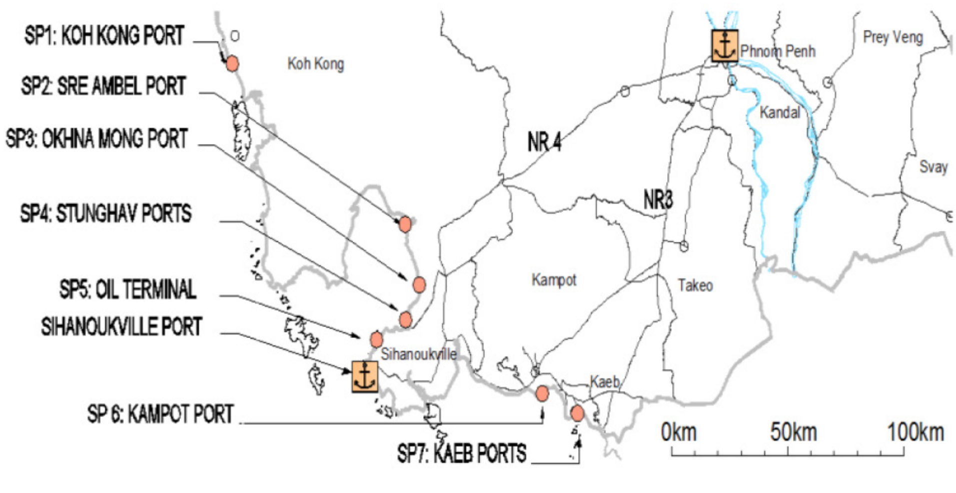
Sre Ambel Port (SP2) Sre Ambel Port is located at Lat:11d 06'921"N / Long:103d 43'607"E in Rondaochhor Village, Sre Ambel District, Koh Kong Province and is 100km from Sihanoukville City and 140km from Phnom Penh. Accessibility to this port could be made by laterite road. Recently the name of the port has been changed to Sre Ambel New Port. Construction of the port started in 2003 and port operation launched on 01st July 2003. It has a total land area of 12 ha (600m x 200m with potential increased to 400ha). Total concrete berth length is 500 m with a width of 30 m and a water depth of 4m. There is a plan to secure a depth of 6m through dredging. SP2 was established by MDH Trading Company. Most imported goods are food and construction materials from Thailand though some originate in Singapore. Cargo throughput is estimated around 10,000 -12,000 tons per month. There are between 3-4 ship calls per month at SP2.

Oknha Mong Port (SP3) The Oknha Mong Port is located in Keo Phos Village, Chroy Svay Commune, Sre Ambel District, Koh Kong Province and is 76 km from Sihanoukville. Port construction started on January 01, 2003 and operations commenced on August 01, 2004. Port has a land area of 64 ha while the total terminal area is about 26 ha. Total berth length is 1,111m with a width of 200 m and a water depth of 4.5m at low tide and 5.5m at high tide. The port is 100% privately owned. Most of the transport is carried out by the wooden boats that carry cargoes from Thailand with the capacity of 300 tons. About 35 to 50 ships call at this port. Most vessels are small size and carry fruits from Thailand (Klong Srun Port). Cement is carried by convoys consisting of 1 tugboat and 4 barges (each with about 1,000 ton capacity). Each month an average of 16 to 20 barges carry cement from Thailand directly from Bangkok.

Stunghav Port and Oil Terminal (SP4 and SP5) Stunghav Port is officially known as Stunghav International Port & SEZ. This port is established by Attwood investment Group Co., Ltd. It locates about 30 km from the main NR4 leading to Sihanoukville city. Port development plan has a maximum water depth of 12m. The land area for port and industries will consist of about 520 ha obtained by reclamation while the basin will be 400 ha, protected by breakwaters of more than 7.6km in length. The volume of materials dredged for the basin and approach channel (in case that the dimension of the channel is 3.7 km in length and 300m in width) is estimated at about 21million m3. The Stung Hav dry cargo terminal is only 50m long with permissible ship draft of only 3.5m to 4.5m in the maximum. Vessel from SP2 mostly carries construction material (350 tons/ship x 7-10 ships/month). Vessels from Thailand, mostly carries general cargo (300 tons/ship x 3 ships/month). All shipments are carried by barges.

Kampot Port (SP6) Kampot Port or Kampong Bay Port is a wooden port and situates in the town on a river bank 4 km from the sea. It is managed by a joint DPWT and Veng Hour Co., Ltd. SP6 is able to take vessels of up to 150 tons or more. It could be accessible by two main approaches from the sea, one of which has fairway depths of 10m to within 11km of the port. The other southern channel could accommodate vessels of less than 4.6m draft. A wooden jetty can be used by 30-40 ton ship. There is another DPWT-managed port, which currently is unused. It locates at Prek Chark, bordering Kaeb and Kampot provinces, close to Vietnam border. It facilities o Berthing point: 10d28'250"N/104d24'000"E , Draft: 4.00m o Entrance channel: 10d27'000"N/104d25'000"E, Draft : 3.50 m o Anchorage position: 10d25'000"N / 104d22'000"E , Draft: 6.00 m

Kaeb Port (SP7) This port is used for passenger to make trip between Kaeb town and islands. Its draft at berth is 2.5m, therefore it is suitable only for small local passenger boats. This port is managed by DPWT of Kaeb. This port could be accessible by good road.



Source: MPWT, 2012

Figure 1-23 Locations of other seaports

Table 1-3 Details of Cambodian local seaports

Source: MPWT, 2012

No.	Port	Water Depth (m)	Investment Company	Investment Scheme	Cost (Million)	Angency	Project Start
SP1	Koh Kong	3-5m	-	-	-	DPWT	1992
SP2	Sre Ambel New Port	4	MDH Trading Company	-	-	Private	2003
SP3	OKNHA MONG	4.5-5.5	Oknha Mong Port Co., LTD	BOO	-	Private	2004
SP4	Port for Petroleum at Stunghav	-	Sokimex		14.5	PAS	2001
SP4	Port for Petroleum at Stunghav	-	Tela Petroleum Group Investment Co., LTD	BOO	30.0	PAS	2004
SP4	Int. Port at Stunghav	3.5-4.5	Attwood Import Export Co., LTD	-	9.0	Private	-
SP6	Int. Port at Kampot	4	Veng Hour Co., LTD	-	-	DPWT	-
SP7	Int. Tourist Port at Kep	-	Aussic-Cam Group Investment and Development Co., LTD (Local)	BOT	-	DPWT	-
SP7	Int. Tourist Port at Kep	-	Rotong Development Co., LTD	BOT	-	DPWT	-
SP7	Commercial Port at Kep	-	Kep Power Supply Co., LTD	BOT	41.0	DPWT	-

DPWT: Department of Public Work and Transport (local brand of Ministry of Public Work and Transport)

BOO: Build Own Operate
BOT: Build Operate Transfer

Among local seaports, Koh Kong port which located near Thai border, received the most ship call (34%) and 72% Gross Registered Tonnage (GRT).

Table 1-4 Statistic data of local sea ports

Source: MPWT, 2012

No.	Port	GC Ship	GRT (t)	GC Ship (%)	GRT (%)
SP1	Koh Kong	213	1,196,372	34	72
SP2	Sre Ambel	194	98,722	31	6
SP3	Oknha Mong	206	202,336	33	12
SP6	Kampot	1	5,264	0	0
SP4,5,7	Others	11	167,867	2	10
Total		625	1,670,560		

1.3 Inland waterway transport and river ports

1.3.1. Present State of River Navigation

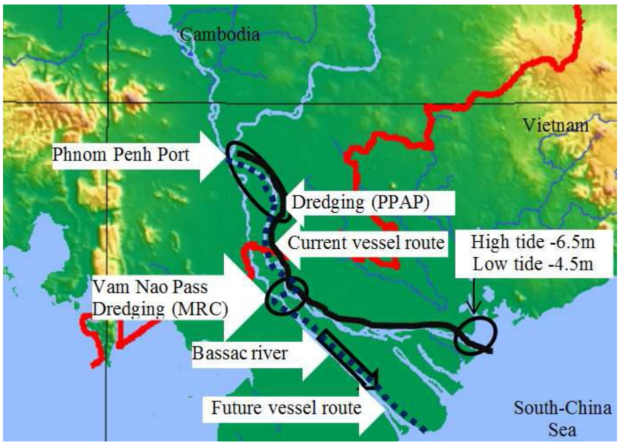
The Master Plan on Waterborne Transport in the Mekong River System in Cambodia, was developed in 2006, by Belgian. The Master Plan set out 60 action plans for the development of inland waterway transport in Cambodia. Some of the action plans are now under implementation. Cambodia's navigable inland waterways measure a total length of 1,750km. Most of the major river ports are located along these major rivers. The Mekong mainstream accounts for 30% of the total, the Tonle Sap River 15%, the Bassac River 5%, and other tributaries 50%. Year-round navigation is possible through 580km long and one third width of the river.

Source: MPWT, 2012

Figure 1-24 Major rivers and domestic river ports

1.3.2. Navigable Vessel Size in Mekong River Channel

For the 102 km stretch between Phnom Penh and Cambodian-Vietnam border, the bends of the river prevent the passage of vessels more than 110m long. To travel from Phnom Penh to South China Sea, currently vessel must take Mekong route in Cambodia and also Mekong route in Vietnam. It has to wait for high tide to pass the most difficult path, which locates at the mouth of the Mekong River. Its water level supports only up to 4,000DWT in high tide and 3,000DWT in low tide.



Source: MPWT, 2012

Figure 1-25 Dredging locations ad vessels movement direction

To take advantage of deep water channel at Bassac River in Vietnam, Cambodia and Vietnam agreed in 2009 that future vessel route will take Mekong route in Cambodia reroute at Vam Nao Pass, use Bassac river in Vietnam. After the completion of dredging at 3 locations in Cambodia (to be done by PPAP financed by Royal Government of Cambodia, RGC) and dredging at Vam Nao pass (by MRC), 5,000DWT cargo vessel can navigate without obstacle in any season.

Table 1-5 describes a summary of bottlenecks and constraints upon inland navigation along the Mekong Basin based on information from the PPAP harbourmaster about the Cambodian territory and collected information about Vietnam territory. **Figure 1-26** also shows a location map of the bottlenecks and constraints upon inland navigation.

As presented in the **Table 1-5** and **Figure 1-26**, Koh Keo Channel (C3), Prek Dach Channel (C5), Koh Ream Rang Channel (C7), Downstream at the end of Peam Island Channel (C8) require widening and deepening (may also require realignment and removal of sunken vessels) in the Cambodia territory, and new pylons are to be constructed for reinstallation of the high voltage line across the waterway between Tan Chau and Xyugen in the Vietnam territory, in order to accommodate 4,000-5,000 DWT class vessels year-around on the waterways.

Furthermore, in order to guarantee safe navigation for larger vessels, it is also required to periodically conduct maintenance dredging based on constant hydrographic surveys, to materialize night navigation with provision of enough navigational aids and mileage posts along the waterways, and to coordinate with local fishermen and communities for harmonized water use.

Table 1-5 Bottlenecks and constraints upon inland navigation along Mekong basin

Source: JICA, 2013

Ref. No.	Location		Bottleneck/Constraint
1C	Cambodia	Chaktomuk Channel	The channel is the access way from Mekong River to Tonle Sap River and versa. It was the famous channel of Cambodian navigator, it consist with the two buoys, which were installed at the edge of the channel. The depth in the Channel was about 5.50m, the width was about 60m and the length was about 1km, but it was become larger and deeper because of sand dredging activities for business.
2C	Cambodia	Dey Eath	It is not small and it's wide big enough for vessel to sail. The depth in the Channel is about 8.0m, the width is about 90m and the length is about 200m.
3C	Cambodia	Koh Keo Channel	The river is large, but it was a dangerous place for navigator. The sand was appeared and spread to more and more place every year, so the channel also changes. Here, when we installed the buoys, and it will be removed them the next year, thus we need often to perform a survey. The channel was made for vessel sail pass at the shallow water. The depth in the Channel is about 6.0m, the width is about 80m and the length is about 1km.
4C	Cambodia	Neak Luoeng Bridge	The bridge will be safe for vessel to sail, because its air clearance will be 37.5m from the highest water of the Mekong River was, and the fairway will be around 300m.
5C	Cambodia	Prek Dach Channel	This is a critical channel for navigation. It was small and sharp bend the way to turn the course of vessel. The vessel was took more dangerous when she was gone follow the current, because of one side edge of the channel is the bank and the vessel must be turned in 90 degree for up and down. The depth in the Channel is about 5.50m, the width is about 80m and the length is about 1.5km. In the new dredging proposal, the new channel will be dredged straightly and shorter than the old, and can facilitate the vessel movement and traffic accordingly.
6C	Cambodia	Peam Chor	It is small, but the access is enough for vessel navigation. The depth in the Channel is about 8.0m, the width is about 100m and the length is about 200m.
7C	Cambodia	Koh Peam Rang Channel	This channel has two buoys red and green installed on the edge of it. It was the critical point to lead avoided a sunken vessel. The depth in the Channel is about 5.50m, the width is about 90m and the length is about 1km.
8C	Cambodia	Downstream at the end of Peam Rang Island Channel	The River is large here, but the route for navigation has limited. The navigation way is on the middle of the river. The areas surrounding the channel are shallow. The course must be leaded by lending marks, which it should be located on the end of Koh Peam Rang (not yet install). The depth in the Channel is about 6.50m, the width is about 80m and the length is about 4km.
1V	Vietnam	Tan Chau - Long Xuyen	The area has a height tension power line which has only 12 meters air clearance.

Note: The above information is not sufficiently covered and updated timely for all bottlenecks and constraints on inland waterway navigation from Phnom Penh and Vietnamese Estuaries due to no detailed investigation and survey conducted.

Source: JICA, 2013

Figure 1-26 Locations of major bottlenecks and constraints upon inland navigation

1.3.1. Present state of Phnom Penh Port

Phnom Penh Port is under the management of state enterprise supervised by MPWT and Ministry of Economy and Finance (MEF). This autonomous enterprise was established by Sub-Decree No. 51, dated 17 July 1998. The Phnom Penh port is the country's traditional river port, accessible by vessels from the South China Sea through Vietnam. Phnom Penh Port is located in the city, along the Tonle Sap, some 3-4 km from its junction with the Mekong.

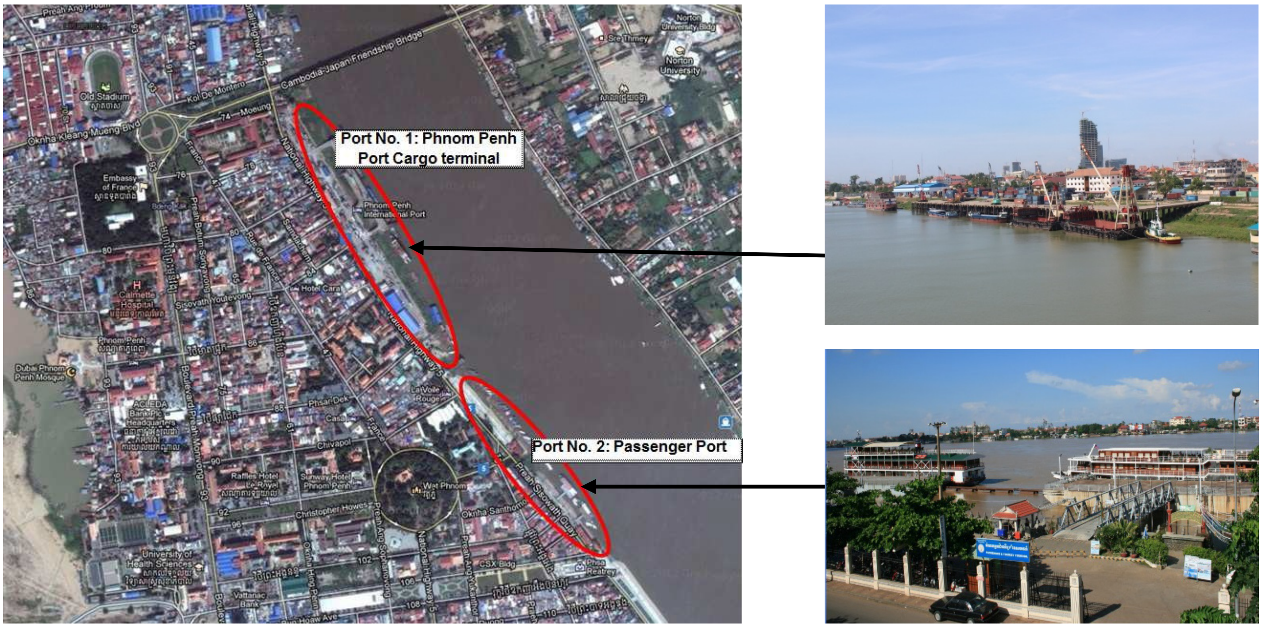
(a) Phnom Penh Port's major infrastructure

Phnom Penh Port is locates at 3 areas: a) Port No. 1 or the main port locates along Tonle Sap about 4km North of Mekong junction, b) Port No. 2 locates about 1km south of Port No. 1 and Port No. 3 locates 30km south of Phnom Penh along Mekong river. Port No.3 was built and operated in the beginning of 2013

Table 1-6 Major infrastructures at Phnom Penh Port

Source: MPWT, 2012

Description	Specification	Remark
Container and General Cargo Terminal	Quay: 20m x 300m	Water depth is -5.0m
	Berthing Capacity: 3 vessels at one time	
Passenger Terminal	2 Pontoons of 15m x 45m each	Water depth is -3.5m
Warehouse	70m x 50m = 3,500m^2	
	50m x 30m = 1,500m^2	
ICD	Area: 92,000m^2	



Source: MPWT (2012), and two pictures (right) are provided in JICA Training Program (2013)

Figure 1-27 Phnom Penh Port's key infrastructures

(b) Km 6 Port and railway connection

There is a port located at Km 6, North of Phnom Penh, between NR5 and Tonle Sap. It was intended for river rail transshipment but this function had ceased. There is a warehouse complex having 15 sheds with a total capacity of 70,000 tons and 8 sheds of nearly 4,000 tons. There is a plan to renew this port to connect to Sihanoukville Port by railway.

c) Services provided by Phnom Penh Port (PPAP)

According to the pamphlet provided by Phnom Penh Port on Dec 2014, there are five major services provided by the port as follows:

1) Handling Services: At the Existing Container Terminal or Phnom Penh Old Port (TS3), the quay is equipped with two floating cranes and three crawler cranes while the New Container Terminal (LM17) is equipped with 3 TCCs for ship-quay operation, and four RTGs at the container yard for more efficiency. PPAP provides handling services 24hours/7days including weekends and national holidays.

2) Warehousing Services: the services are offered to all customers for consolidating and de-consolidating goods, two modern warehouses at PS3 and one bonded warehouse of 22 hectares at LM17.

3) Inland Container Depot (ICD): As the container traffic continues to increase annually, PPAP has acquired 9 hectares of land to serve as an ICD located 4 km away from the TS3 for storing both empty and laden containers for free of charge Furthermore, the ICD also offers warehousing facility to be leased for storing agriculture warehousing facility to be leased for storing agriculture products as well as other types of products.

4) Passenger and Tourist Terminal: To meet the inland water way tourism demand, PPAP has improved this terminal by building passenger's waiting facility, which includes coffee shop, souvenir shop, and restaurant. With this terminal, passengers can enjoy both domestic and international cruises as well as short city tour along the rivers.

5) Surveying and Dredging Services: PPAP operates two dredgers with the capacity of 380 m3/h and 170 m3/h. These dredgers are used to regularly maintain the access channel of all the navigation routes in order to allow smooth navigation of vessels all year round. These dredgers are also available for commercial use to provide the land or sand reclamation services.

(d) Ship calls at Phnom Penh Port

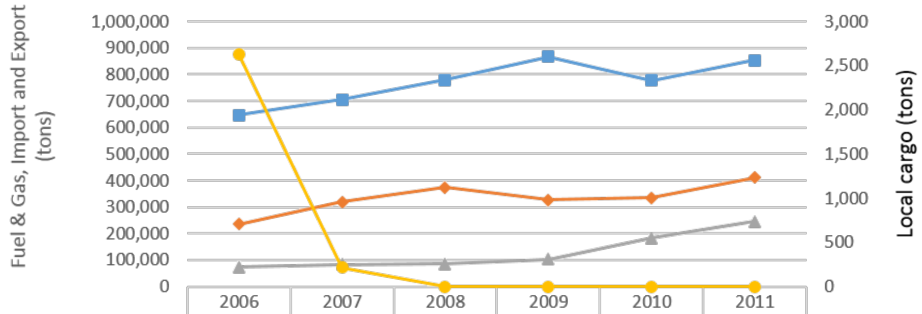
Several shipping companies made called at Phnom Penh Port with the total ship calls of 16 per week as of June 2014 (Kume, 2014).

Table 1-7 Ship calls at Phnom Penh Port (as of June 2014)
Source: Kume (2014)

Shipping Company	Departure from Phnom Penh Port	Calling Ports		Import Container (TEU／month)	Export Container (TEU／month)
Gemadept Sovereign Base Logistics SNP-Cypress	7calls／week（Sun、Wed)	Phnom Penh -Cai Mep – Ho Chi Minh - Phnom Penh		1,100（Laden) 1,300 (Empty)	2,300（Laden) 90 (Empty)
	3 calls ／week (Sun)			630　Laden) 380 (Empty)	1,150（Laden) 10 (Empty)
	6 calls／week (Sun、Wed)			1,700（Laden) 1,200 (Empty)	2,800（Laden) 140 (Empty)
Total	16 calls／week			3,500 (Laden) 2,900 (Empty)	6,200 (Laden) 240 (Empty)

(e) Phnom Penh Port's cargo throughput

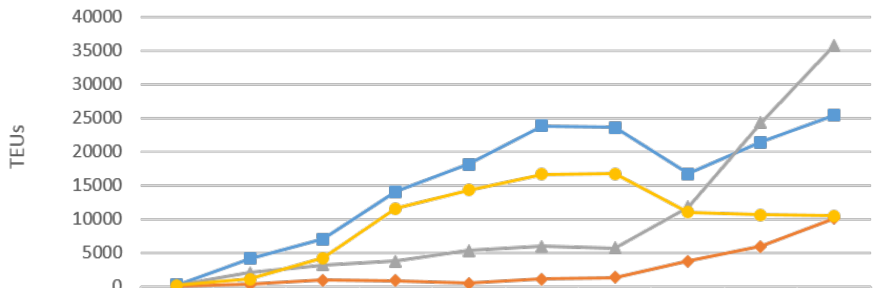
There is only data of Phnom Penh usage is available. Most of Phnom Penh Port service is used for maritime trade service (import and export). Local cargo has ceased to operate since 2008.



	2006	2007	2008	2009	2010	2011
Fuel & Gas (tons)	646,325	704,501	780,036	867,943	777,868	852,716
Import (tons)	234,487	318,367	374,277	326,114	334,443	411,468
Export (tons)	72,725	83,620	86,026	103,058	182,489	244,229
Local cargo (tons)	2,633	213	0	0	0	0

Source: MPWT, 2012

Figure 1-28 Import & export trends at Phnom Penh port



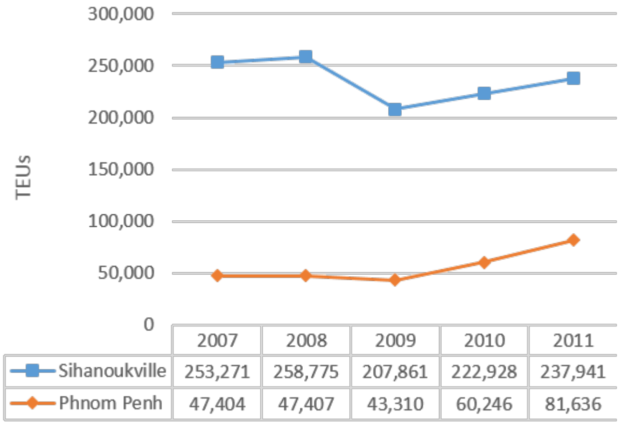
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Import Laden	242	4,134	7,054	14,077	18,099	23,783	23,623	16,735	21,369	25,344
Import Empty	100	306	985	867	477	1,126	1,387	3,769	5,940	10,124
Export Laden	237	2,072	3,237	3,767	5,341	5,942	5,743	11,775	24,276	35,696
Export Empty	167	1,118	4,250	11,570	14,316	16,653	16,754	11,033	10,671	10,467

Source: MPWT, 2012

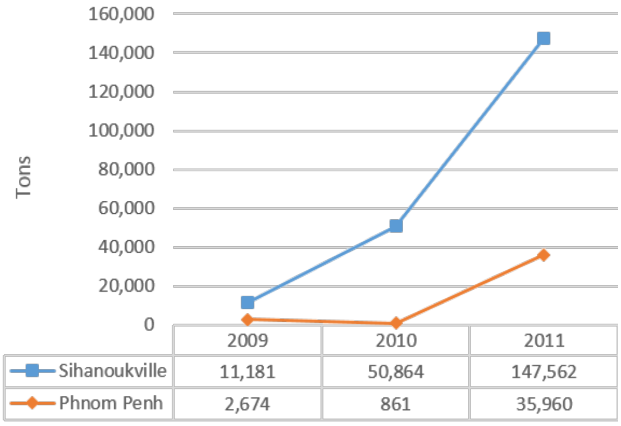
Figure 1-29 Trends of ration of empty and laden containers at Phnom Penh Port

Phnom Penh and Sihanoukville Ports are two major ports in Cambodia. Both of them were hit hard by world economic recession in 2008-2009 but Phnom Penh Port's business health bounced back. By end 2009, it had caught up with its pre-recession level and continues to growth annually and almost double the pre-recession output by year 2011.

This indicates that Phnom Penh Port presents strong economic growth. Concerning rice export, in the last three year (2009-2011), rice handling volume at both ports increased by more than 10 times.



	2007	2008	2009	2010	2011
Sihanoukville	253,271	258,775	207,861	222,928	237,941
Phnom Penh	47,404	47,407	43,310	60,246	81,636



	2009	2010	2011
Sihanoukville	11,181	50,864	147,562
Phnom Penh	2,674	861	35,960

Source: MPWT, 2012

Figure 1-30 Trends of container (TEUs) at Phnom Penh and Sihanoukville Ports

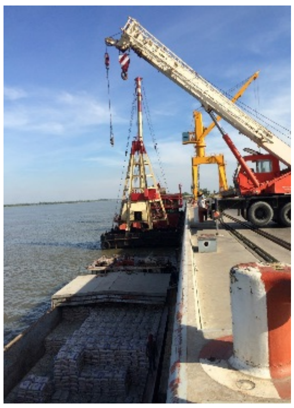
Figure 1-31 Trends of rice (bulk and containerized) export at Phnom Penh and Sihanoukville Ports

(f) New Phnom Penh Port and Special Economic Zone (SEZ) plan

1) Because of several restriction to run No.1 and N.2 ports such as low water level, traffic congestion as well as their capacities are getting full, New Phnom Penh Port or the No.3 port is being constructed 25km downstream from the No.2 ports (between National Road No.1 (NR1) and Mekong river). This is a 28-million USD project funded by China.
   - Contractor: Shanghai Construction (Group) General Company
   - Construction Period: 30 months (Construction of infrastructure)
   - Request further budget to finance superstructure
   - Initial capacity: 120,000 ETUs/Year
   - Total Capacity = 300,000 TEUs/year (including future plan)
   - Berth = 22m x 300m, Port Area = 12 ha
   - SEZ plan: To support New Container Terminal (NCT), PPAP is planning to develop SEZ. This project is under preparatory survey by JICA.
     - Infrastructure : Bonded Warehouse, Agricultural Processing Zone and Industrial zone
     - Location : NR1, PK : 30, opposite side of current New Container Terminal
     - Size : Approximately 200ha

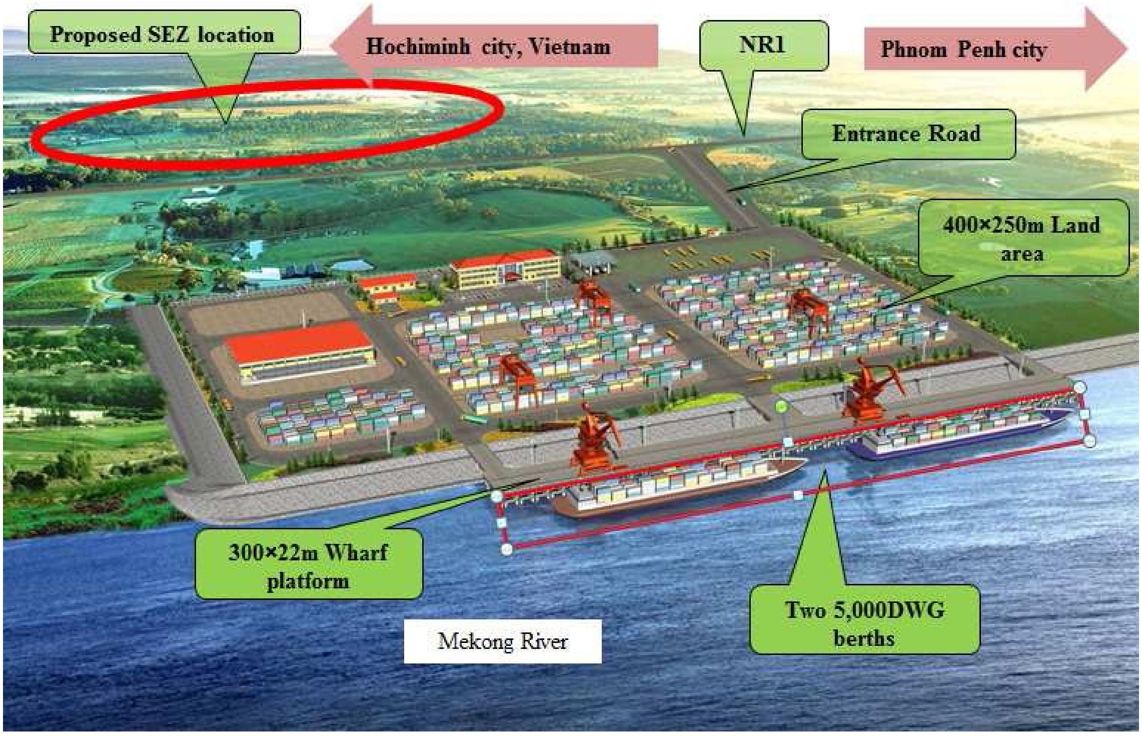
(Photo taken by author)

Figure 1-32 Container yard of New Phnom Penh Port



(Photo taken by author)

Figure 1-33 Cargo handling activity

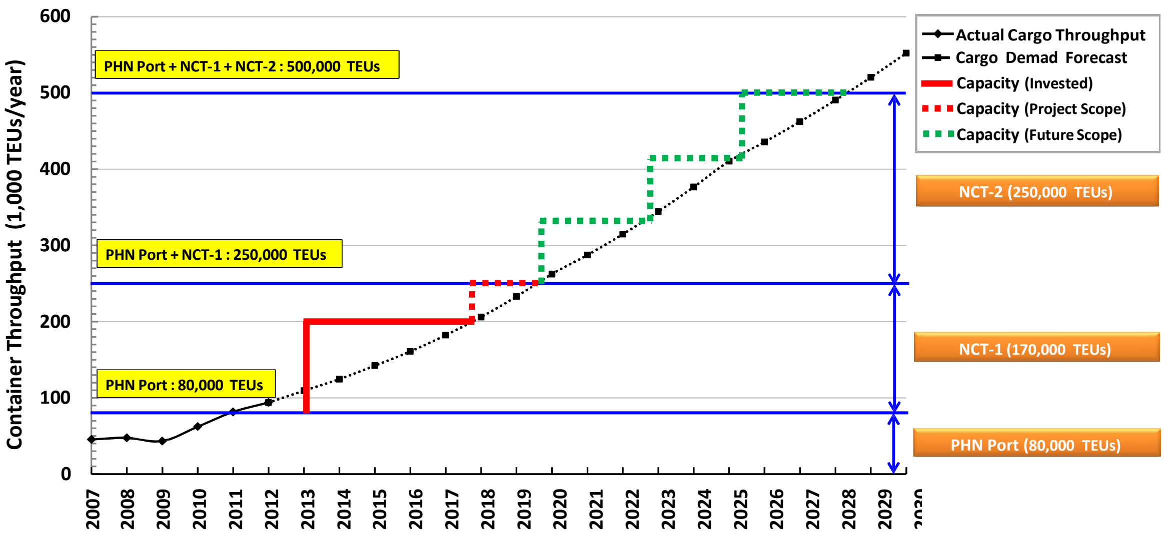


Source: PMWT, 2012

Figure 1-34 New Phnom Penh Port and Special Economic Zone (SEZ) plan

(g) Port expansion scenario based on Cargo demand forecast

As shown in **Figure 1-35**, port expansion scenario based on cargo demand forecast was studied by JICA expert for the preparatory survey on the future plans of port development (JICA, 2013). The volume of container through at Phnom Penh (old) Port (PHN Port) reached port's capacity of 80,000 TEUs in 2012. Then, the New Container Terminal (NCT-1) was built for the capacity of 170,000 TEUs for the demand up to 2020 (PHN Port + NCT-1: 250,000 TEUs). After that, the New Container Terminal (NCT-2) will be constructed for the capacity of 250,000 in order to fulfil the total demand of 500,000 (PHN Port + NCT-1 + NCT-2) by 2028.



Source: JICA, 2013

Figure 1-35 Port expansion scenario based on cargo demand forecast (2007-2030)

1.3.4 Other River Ports

Excluding Phnom Penh Port, 6 major river ports are located along Cambodia's river system. Three ports are located in the Tonle Sap River and other three located in Mekong River (refer to **Figure 1-13** in **Section 1.1.3** of the main report).

- **Stung Treng Port:** Stung Treng port, locates in Stung Treng Province, is an important regional center, located where the Sekong joins the Mekong and also with road access both to Laos (Road 7) and the Vietnam (Road 78). A ferry brings the traffic along Road 7 across the Sekong, but is not much used in the present security situation. The Sekong and its tributaries Sesan and Srepork provide the only mean of access to most parts of the Stung Treng and Rattanakiri provinces. Some 130 boats are registered in Stung Treng including about 50 in the range 10-35 tons. There is no dedicated port facilities, however. The river banks have to be used or during the low water season the temporary jetty is to be provided for the ferry.

- **Kratie Port:** As Road 7 is very poor and indirect, most of the current traffic between Phnom Penh and Kratie is carried by river. Kratie is a provincial capital and another important centre for the rubber trade. The port has a 35m long pontoon, used only in the rainy season, and a 1,000m2 warehouse said to have a capacity up to 5,000 tons.

- **Kampong Cham Port (or Tonle Bet Port, 106km):** Tonle Bet port, locates in Kampong Cham province, which is one of the most important provinces in Cambodia. It is situated on a cross-roads of two main trading routes: north-south along the Mekong from Laos to the sea, and east- west between Thailand and Vietnam along the historic route via Siem Reap. It is growing quickly and is an important centre for the rubber plantations. Much of the transport to and from Phnom Penh is by river. There is a passenger landing and a 10m long pontoon for barges up to about 400 ton capacity. During the dry season the pontoon is grounded and the river bank is used. There is also a warehouse with a covered area of 550 m2, said to have a capacity of about 600 tons. Across the river from the town, on the left bank, there is some 5,700 m2 of open storage area.

- **Kampong Chhnang Port (or Phsar Krom Port or Chhnok Trou Port):** Kampong Chhnang port locates on the Tonle Sap River, between Phnom Penh and the Great Lake. It has a fishing port at Chhnok Trou and is also a market town for a rather large area on both sides of the Tonle Sap, and lake. Much of the boat traffic transships between road and river, for journeys to/ from Phnom Penh. The port facilities are congested, with a large adjacent market area, and the whole area needs improvement and paving. At present, however, the function of the port is more of a provincial one than a national one, as larger vessels cannot enter the lake in a low water season.

- **Pursat Port:** It has a fishing port at Krakor, which is an important site at the south-east corner of the Tonle Sap Lake. It is important for fishing but also as transshipment point between boats and road transport for journeys between Siem Reap and Phnom Penh. Unlike the River Sap, the lake is navigable the whole year and is used both for passenger and goods traffic. Most of this traffic uses Road 5 to and from Phnom Penh.

- **Siem Reap Port (or Chon Khneas Port):** The port for Siem Reap is located 5 km from the city and can only be used at high water. During the dry season the water level may be as much as 10 m lower and up to 11 km from the port. An access road (which is totally inundated at high water) then connects the town to the lake. A temporary wooden port is constructed at the beginning of each dry season but is destroyed together with any improvements to the access road as the water rises. There are also various mooring places along the access road for intermediate water levels. The port is mainly used for goods traffic to/from Phnom Penh either directly via the Tonle Sap River or with transshipment in Krakor or in Chhnok Trou in the southern end of the lake. Some 12 passenger boats also ply the route and there are some new express services for tourists to Angkor Wat.

国土技術政策総合研究所資料

TECHNICAL NOTE of N I L I M

No. 833　　　　　March 2015

編集・発行　©国土技術政策総合研究所

本資料の転載・複写のお問い合わせは

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