Evaluation of Natural Disaster Conditions between Japan and Cambodia for Port Structure Design

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This research aimed to develop official port design standards for Cambodia by modifying and harmonizing that of Japan to be suitable for Cambodia’s conditions. At this stage, we focused mainly on natural disaster conditions that may affect port structure design. Thus, in this paper, (1) the differences of natural disaster conditions between Japan and Cambodia: earthquake, typhoon, and flood, were evaluated to estimate the conditions for port structure design. (2) The effects on port structure design from the differences of the above conditions were evaluated. The evaluation was carried out by applying the Japanese Technical Standards for the selection of suitable structural types of quaywall among concrete block, concrete caisson, steel pipe pile, and steel sheet pile. Three criteria were used for the selection of suitable structural types: applicability against natural disaster conditions, construction cost, and constructability of each structure.

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

1. INTRODUCTION

Since there is no design standards in Cambodia, most of major port development projects have been carried out using design standards from donor countries (e.g., France, Japan, China, etc.) through the Official Development Assistance (ODA). This may lead to uneconomical and technically inappropriate designs because those standards may not be suitable for Cambodia’s conditions.

According to the above situations, 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) to be suitable for Cambodia’s conditions. In this paper, natural disaster conditions that may affect port design were mainly focused by: (1) differences of natural disaster conditions: earthquake, typhoon, and flood between Japan and Cambodia were evaluated for the estimation of conditions for port structure design. Then, (2) referring to the effects regarding the differences of disaster conditions between both countries, Japanese Technical Standards were applied for the evaluation of suitable structural types of port facilities. The evaluation was carried out by applying the estimated design conditions against natural disasters to Japanese Technical Standards. Four different structural types of quaywall were considered in 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 was based on the consideration of the following three criteria: applicability against natural disaster conditions, construction cost, and constructability of each structural type.

2. EVALUATION OF NATURAL DISASTER CONDITIONS

(1) Earthquake

Based on various studies and international databases, there were no earthquakes have occurred in Cambodia. Therefore, it is safe to say that Cambodia...
has no or little effect from earthquakes, particularly on port facilities. However, in Japan, which is regarded as one of the world’s most earthquake-prone nations, port facilities are exposed to earthquakes as well as tsunamis\(^4\). Thus, Japanese Technical Standards were developed with strict considerations of the effects of natural disasters, particularly earthquakes.

In stability analysis against earthquakes, horizontal seismic coefficient (\(kh\)) is used to calculate seismic load by multiplying \(kh\) to deadweight or sum of deadweight and surcharge\(^4\). In Japan, the value of \(kh\) varies from 0.05 to 0.27, was estimated from a product of the regional seismic coefficient (0.08-0.15), the soil-type coefficient (0.8-1.2), and the importance coefficient of structure (0.8-1.5)\(^4\).

In case of Cambodia, as for this study, \(kh\) was estimated by using equation (1) that applicable to peak ground acceleration (PGA) of 2.0 m/s\(^2\) or lower\(^4\).

\[ kh = \frac{\alpha}{g} \]  

(1)

where \(kh\): horizontal seismic coefficient  
\(\alpha\): peak ground acceleration (m/s\(^2\))  
\(g\): gravitational acceleration (g=9.81 m/s\(^2\))

The range of PGA in Cambodia was estimated using the PGA database map (Fig. 1) provided by Global Seismic Hazard Assessment Program\(^5\). As shown in Fig. 1, PGA in Cambodia of 0.2 to 0.4 m/s\(^2\) was assumed. By applying the PGA to the above equation (1), as a result, \(kh\) for Cambodia varies from 0.02 to 0.04. This study suggests, therefore, the \(kh\) of 0.05 or lower for port structure design in Cambodia.

(2) Typhoon

In typhoon data analysis, we estimated typhoon wind speed and typhoon-generated wave height with a return period of 50 years. The typhoon data in Cambodia and Japan were derived from typhoon databases provided by Joint Typhoon Warning Center (JTWC)\(^6\) and Japan Meteorological Agency (JMA)\(^7\), respectively. Typhoon data in Japan were available on JMA’s homepage. Since, there was no available typhoon data in Cambodia, it was necessary to define them from databases provided by JTWC.

a) Definition of typhoon data in Cambodia

To define typhoon database for Cambodia, the below conventional terms (derived with reference to JMA regardless wind speed/pressure) were used.

- Landing typhoon: typhoon whose center entered into Cambodia’s border.
- Approaching typhoon: typhoon whose center entered into the area within about 300 km (inside dashed-line box, Fig. 2) from Cambodia’s border.

As a result, the typhoon statistical data were derived for the period of 63 years (1951-2013) for Cambodia (Fig. 3). With a total number of 1,650 of typhoons occurred in Western North Pacific Ocean, 165 typhoons have approached to Cambodia (average: 2.6 typhoons/year) and 30 typhoons have landed on Cambodia (average: 0.5 typhoons/year). Based on the Saffir-Simpson Scale, all typhoons landed on Cambodia vary within the category of only Tropical Depression (TD) and Tropical Storm (TS).

b) Estimation of return wind speed

Based on the databases provided by JTWC, wind speed of typhoons were obtained. Only peak wind speed (of typhoon’s center) data of typhoons landed
on Cambodia were used in this study. Thus, there were 20 number of peak wind speed $U$ (15-55 knots) data among the total number of 30 typhoons landed on Cambodia. During statistical processing, the wind speeds were arranged in the descending order ($m$-th), and the probability $P$ (non-exceedance probability that wind speed does not exceed $x_m$) was calculated using the following equation (2)$^9$:

$$P(U \leq x_m|N) = 1 - \frac{m - \alpha}{N - \beta}$$  \hspace{1cm} (2)

where $x_m$: the $m$-th peak wind speed ranged from 1 to total number of data $N$ (N=20)  
$\alpha$, $\beta$: parameters of distribution function

By assuming that the data fits Weibull distribution function, $\alpha = 0.39$, $\beta = 0.37$ for the case of $k=2.0$, gave the largest correlation coefficient of 0.972.

As a result, non-exceedance probability of wind speed data was estimated as shown in Fig. 4 (top).

The return period ($R_p$) of $U$ was estimated with relation to $P$ by using the equation (3)$^{10}$:

$$R_p = \frac{K}{N - 1} \frac{1}{1 - P(U \leq x)}$$ \hspace{1cm} (3)

where $K$: duration that data used, $K=63$ years.

As a result, the estimated wind speed with a return period of 50 years is 50 knots (Fig. 4, bottom).

c) Estimation of significant wave height

By considering the geographical condition around Cambodia's seaports, Mitsuyasu Type II Spectrum was chosen for the estimation of typhoon-generated wave height by applying the equation (4)$^{10}$:

$$s(f) = 8.58 \times 10^{-4} \left( \frac{g F}{u_*^2} \right)^{0.312} g^2 f^{-5} S(f)$$ \hspace{1cm} (4)

By applying the above estimated wind speed of 50 knots (25.70 m/s), the wave frequency spectrum was calculated as shown in Fig. 5.

Significant wave height ($H_{1/3}$) and period ($T_{1/3}$) were estimated by using the following equations$^{10}$:

$$H_{1/3} = 4.004 \sqrt{E}$$ \hspace{1cm} (5)

$$T_{1/3} = 1/1.05 f_p$$ \hspace{1cm} (6)

where $E$: wave energy, $E=a$ summation of $S(f)$

As a result, the significant wave height ($H_{1/3}$) and period ($T_{1/3}$) were estimated as shown in the Table 1. By considering the local fetch around Cambodia’s seaports of about 50 km, therefore, the $H_{1/3}$ and $T_{1/3}$ were estimated to be 3.9 m and 7.3 s, respectively.

(3) Flood

The maximum and minimum water levels, recorded between 1980 and 2013, were provided by the Ministry of Water Resources and Meteorology (MOWRAM), Cambodia$^{11}$. Using annual maximum water levels in Bassac-Chak Tomuk station (closest to Phnom Penh Port), the maximum flood water level was estimated following the procedures and considerations used in typhoon analysis in Section (2), b.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
\textbf{F (km)} & 10 & 25 & 50 & 100 & 200 \\
\hline
$H_{1/3}$ (m) & 1.8 & 2.8 & 3.9 & 5.6 & 7.9 \\
$T_{1/3}$ (s) & 4.3 & 5.8 & 7.3 & 9.2 & 11.5 \\
\hline
\end{tabular}
\end{table}

Fig. 5 Mitsuyasu frequency spectrum

Table 1 Results of $H_{1/3}$ and $T_{1/3}$
The non-exceedance probability and return period of water levels were estimated as shown in Fig. 6. With a return period of 50 years, water level was estimated to be 11.66 m, which is about 10 m different from average minimum water level in dry season.

(4) Data analysis results and considerations

According to the above evaluation results and considerations, the differences of the natural disaster conditions between Japan and Cambodia were summarized as shown in Table 2.

3. EFFECTS FROM THE DIFFERENCES OF NATURAL DISASTER CONDITIONS ON PORT STRUCTURE DESIGN

(1) Evaluation criteria

This section discusses the effects of the differences of natural disaster conditions between Japan and Cambodia on port structure design. The effects were evaluated through the comparison of suitable structural types of port facility between both countries. The evaluation was carried out by combining three criteria, i.e., applicability against natural disasters, construction cost, and constructability.

a) Applicability against natural disasters

The applicability of each structure was discussed by analyzing the stability of each structure against the disasters. Therefore, the stability design was carried out by varying \( kh \) from 0.05 (as for Cambodia) to 0.27 (as for Japan). The estimated \( H_{1/3} \) and \( T_{1/3} \) were not considered because the studied structure was quaywall in which wave is usually negligible. Flood was considered for river port design by considering water levels in flood and draught conditions.

b) Construction cost

The cost of each structure was calculated using the material quantity required in the above stability design. Items to be considered for cost calculation were quantity of each structure itself, quaywall foundation and dredging works, backfill stone and sand, and structure for crane’s rail foundation, except steel pipe pile structure. The material unit prices in Cambodia provided by JICA\(^ {12} \) were used for mixed concrete, structural steels, filling materials, rubble stone, and dredging works, while those in Japan\(^ {13} \) were used for reinforced concrete, steel pile, and tie rod.

c) Constructability

Various factors may contribute to the constructability of each structure type. However, in this study, we considered major factors such as heavy equipment/work vessels, skilled labor/engineer, and construction materials.

(2) Design calculation of quaywall

a) Design calculation criteria

The Japanese Technical Standards were used for the design calculation of the quaywall structure. The design conditions regarding the natural disasters were considered based on the above analysis results.

Table 2 Differences of design conditions for port facilities

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

*The Saffir-Simpson Scale [Cat.: Category, TS: Tropical Storm]

Table 3 Design conditions and parameters

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Seaport</th>
<th>River Port</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crest height</td>
<td>+3.0 m</td>
<td>+9.5</td>
</tr>
<tr>
<td>Design depth</td>
<td>-13.5 m</td>
<td>-8.5 m</td>
</tr>
<tr>
<td>Ship size</td>
<td>50,000 DWT</td>
<td>5,000 DWT</td>
</tr>
<tr>
<td>Distributed load</td>
<td>30 kN/m² (Ordinary condition)</td>
<td>15 kN/m² (Earthquake condition)</td>
</tr>
<tr>
<td>Gantry crane size</td>
<td>Post Panamax</td>
<td>Below Panamax</td>
</tr>
<tr>
<td>Sea/river bottom</td>
<td>-8.6 m</td>
<td>-7.0 m</td>
</tr>
<tr>
<td>Sub-soil (N: SPT value; d: depth)</td>
<td>N=0-5(d: 0-4m)</td>
<td>N=0-5(d: 0-10m)</td>
</tr>
<tr>
<td>Water Levels (Low Water Level: L.W.L=0.00m)</td>
<td>Mean Sea Level: L.W.L+0.60 m</td>
<td>Mean Water Level: L.W.L+0.65 m</td>
</tr>
<tr>
<td>Wave, current, flow</td>
<td>Not considered</td>
<td></td>
</tr>
<tr>
<td>( kh )</td>
<td>0.05 – 0.27</td>
<td></td>
</tr>
</tbody>
</table>
and considerations. Other conditions and parameters in Table 3 were obtained from the existing conditions used for the real designs of major ports in Cambodia, i.e., Sihanoukville Port (largest seaport) and Phnom Penh (New) Port (largest river port).

b) Cross sections of the evaluated structural types

Concrete block type quaywall has been adopted for Sihanoukville Port while steel pipe pile type quaywall has been adopted for Phnom Penh (new) Port. As shown in Fig. 7, four types of structures of quaywall were considered in the evaluation: concrete block (CB), concrete caisson (CC), steel pipe pile (SPP), and steel sheet pile (SSP).

(3) Evaluation of suitable structural types corresponding to the design calculation results

a) Applicability

The calculation results of CB and CC are expressed as in width of quaywall while that of the SPP are expressed in diameter and total weight of required steel pipes (Fig. 8). Whilst, only diameter and weight of front sheet pipe piles are shown for SSP. In case of CB and CC (Fig. 8, top), the required width of quaywall slightly increases for low to moderate earthquake ($kh=0.05-0.17$), but sharply increases for moderate to strong earthquake ($kh>0.19$). In case of SPP and SSP (Fig. 8, bottom), required diameters and weights slightly increase following the $kh$ value.

Based on these results, all structural types are “applicable” for regions with low to moderate earthquake. However, for regions with strong earthquake (as in Japan), CB and CC are “not applicable” while SPP and SSP are “applicable”.

b) Construction cost

The construction cost (per 1 meter in the length of quaywall) of the four structural types were estimated (Fig. 9). In general, the cost slightly increase following value of $kh$. The cost of CB and CC sharply increases for $kh$ over 0.19. It is notified that the trend of cost drops, although $kh$ is increased (e.g., the cost CC where $kh=0.21-0.23$) because the width of quaywall become larger than the span of legs of gantry crane. Thus, foundation for gantry crane is not required so that it was excluded in cost estimation.

In comparison, the cost was classified as: “cheap” if it is equal to or less than 2.0 million yen/m; “moderate” if it ranges from 2.0 to 3.0 million yen/m; “expensive” if it is over 3.0 million yen/m.
d) Constructability
The constructability classified as the “most constructable”, “constructable”, and “not constructable”. By combining these three factors as described in section (3), CB is the “most constructable” because it requires simple equipment and materials as well as workers. CC is “not constructable” because it requires large-scale work vessels/heavy machines for production and installation of caisson. The mobilization and demobilization of those heavy equipment require high cost. SPP and SSP are “constructable”, though medium scale pile driving machines are available from the nearby countries, but the materials, e.g., steel pipe, must be imported from overseas.

e) Summary of evaluation results
By combining the above criteria, the suitability of each structural types of quaywall for ports in Cambodia and Japan were suggested (Table 4). These results are limited to the conditions and assumptions of Sihanoukville Port and Phnom Penh Port.

Since the design conditions and parameters varies case by case, these results may not applicable to other cases. If these results are subjected to be applied to other cases, more case studies should be carried with different design conditions and parameters, e.g., vessel size, scale of structure, subsoil condition, etc. In addition, more types of structures shall be evaluated for selection of suitable structure types.

4. CONCLUSION

1) Natural disaster conditions in Cambodia were estimated as follows: (1) Earthquake: horizontal seismic coefficient, \(kh\leq0.05\), which is much smaller than that in Japan where \(kh=0.05-0.27\). (2) Typhoon: maximum wind speed, \(U=25.7\ \text{m/s}\) (i.e., Tropical Storm); and significant wave height, \(H_{1/3}=3.9\ \text{m}\). This value of significant wave height is smaller than that in Japan. (3) Flood: maximum water level, \(W_m=11.65\ \text{m}\) which is about 10 m of annual fluctuation. The value of flood range is larger than that in Japan.

2) Suitable port structure design in Cambodia, under limitations and assumptions in this study, were suggested as follows: (i) effects of earthquake and typhoon may not be considered; (ii) effects of flood are required to 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.

In this case study, suitable structural types were evaluated as follows: concrete caisson and steel pipe pile are “suitable” and steel sheet pile is “not suitable” for both seaport and river port. Concrete block is “suitable” for seaport, but “not suitable” for river port because of large seasonal fluctuation of water levels.

For future work, other costs (e.g., labor, equipment, maintenance, etc) 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-labor/engineer, equipment, materials, etc.

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