Design of Taiwan Friendship Bridge River Tempisque, Costa Rica

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1. Introduction

Taiwan Friendship Bridge spans over Tempisque river connecting the tourist attraction area, Nicoya Peninsula, to mainland Costa Rica. It is an important landmark at the Guanacaste area and upon completion, it will significantly improve tour business and transportation flows and hence strengthens the economic developments of Costa Rica.

This 780 meter long and 13.3 meter wide bridge includes two design sections: a 260 meter cable-stayed bridge on the west side, and a 520 meter composite box-girder bridge on the east side. The cable-stayed bridge is orchestrated with a single H-type pylon and nine cables in each side spanning asymmetrically to present a volcano-like landmark. This section spans over the deepest part of river with a height clearance of 10 meter for safe shipping navigation. The composite box-girder bridge, consisting of reinforced concrete deck and open steel box-girder, is arranged into eight 65-meter spans. It stretches over the shallow side (east) of the river and maintains a clearance at least 5 meter to clear the high tides from Nicoya Gulf.

Since the bridge site is in a strong earthquake zone, the seismic design has been considered specially to comply with the Seismic Code of Costa Rica (1986), other than the Standard Specifications for Highway Bridges of AASHTO (16th Edition). Base on the investigated geo-technical information, casing pile foundation and caisson (pylon only) are selected to provide the required bearing capacity.

To minimize risk and the environment impact during construction, the Segmental Launching Technique is recommended for the erection of main girders. Temporary piers will be used to launch the girders and ease the difficulty of erection and adjustment of the cables.

2. Site Environment

It is a beautiful scene of tropical woods around the bridge site, where the Bebedero river just flows into Tempisque river. The hydrology near this bridge is influenced by the precipitation areas of both rivers, besides the fluctuation of tides. Base on the gathered information, the average raining season starts from May and ends November. During this season, the average water level is about 2 meters higher than that in the dry season. Adding the average 3 meters H/L-tide difference, the average High Water Level at EL. +2.85 meter can be 5 meters higher than the average low water level in the dry season. The weather is mild at this tropical area, where temperature is between 15 ^{o}C and 35 ^{o}C; the maximum wind speed is 75 miles per hour according to the meteorology records.

The subsoil along the bridge alignment is found consisting with two major layers, alluvial soil layer and rock layer, after a thorough investigation. The alluvial soil covers 80% of riverbed in east side, where the depth of water is shallow. The rest of riverbed is consisted with rock only, where is also found the deepest water under the bridge. The rock layer is taken as bearing layer of bridge foundation. However the site is located in a relative strong earthquake zone, where the maximum ground acceleration for 1000-year risk period is near 0.325g, according to the Isoacceleration map adapted from Codigo Sismico de Costa Rica, 1986.

3. Design Development

The design of Taiwan Friendship Bridge has been developed through several stages. At first, the width of bridge is decided to be 13.3 meters, which is wider than most of the connecting roadway (8 meter wide), for future roadway widening. Since the alignment shall coincide with roadway, the distance cover regular water zone (bank to bank) along the central line of bridge is about 716 meters. Considering the safety during raining season, a total length of 780 meters is rendered for this bridge.

Secondly, it is always required to reserve a long span and height

clearance for navigation, when a bridge is designed to cross over a major waterway such as Tempisque River. In this bridge the longest span of 170 meters is arranged over the deepest water section, where is also reserved the largest height clearance of 10 meters. Furthermore, the rest sections are also rendered a minimum height clearance of 5 meters to prevent any possibility of direct impact of fluid on the girders.

Next, since this bridge is built to be a landmark, the aesthetic outlook is studied thoroughly with economical consideration. A regular steel I-girder bridge has been presented first, base on the economical and technical point of views. Nevertheless, the outlook is too flat to stand out as a landmark, although it is inexpensive and rather ease to build. Meanwhile, the other types of bridge such as steel truss, concrete arch, steel arch, suspension, and cable-stayed bridges are considered during the aesthetic study. The asymmetric cable-stayed bridge type is selected due to its volcano-like outlook, which reflects the famous scene of volcano Arenal. Other types are eventually out of competition due to aesthetic, construction, maintenance, and economical consideration. Among those, arranging a long span tied arch over the deepest water zone had been considered seriously, but it looks awkward and does not have a height to be a landmark.

After the type of main bridge is selected, the profile of bridge is arranged as follows: First, the length of single pylon asymmetric cable-stayed bridge, which spans over the deepest water zone, is decided to be 260 meters (1/3 of total length), for the aesthetic and economical considerations. Aesthetically, the clearance from average High Water Level to the bottom of bridge is relatively shallow (10 meter height), base on the profile of bridge; it will not present an aesthetic out look, if the length is too long. Economically, the construction cost of cable-stayed bridge is normally more expensive than that of steel girder bridge.

The rest of bridge (2/3 of total length) is decided to be a composite (concrete deck with open steel box-girder) box-girder bridge, after the seismic, aesthetic and maintenance considerations. The conical line of composite box-girder is much better and the maintenance is rather easier comparing with

the steel I-girder. Also the weight, which affects directly the seismic load, is much lighter than that of concrete box-girder. Furthermore, an optimization study of span length has been done to minimize the construction cost including its superstructure and substructure. As a result, the steel box-girder is divided into 8 equal spans of 65 meters. It makes only 8 piers, besides the foundation of pylon, in the Tempisque river; and the depth of superstructure is relatively shallow, and hence the cost is minimized.

4. Seismic Design Consideration

Earthquake occurred recently in 1990, center near the end of Nicoya peninsula along fault called CR-16 magnitude 7.1R.scale provide hints to our seismic design. Dynamic analysis has been conducted with adapting the local specific spectrum and horizontal acceleration of 0.325g. The support lengths at both abutments and piers are designed to be at least 1.5 times of the minimum required length to secure the safety under seismic conditions. There are three seismic units total, two in steel box-girder bridge and other one is the cable-stayed bridge. The FAD (Dynamic Amplification factor) values for both rock and soft soil in Codigo Sismico de Costa Rica, 1986 is also used in the analysis, which gives worse seismic load than that is calculated according to the AASHTO specifications.

5. Steel Box-Girder Bridge

It is divided into two seismic units, each units consists of four equal spans. After a Value-Engineering study, the connection arrangement between superstructure and substructure is chosen to be M (moveable) – F (fix) – F – F – M for both structural units to get the best homogeneous in stress distribution of piers.

6. Cable-Stayed Bridge

The cable-stayed bridge is spanning over the deepest water zone of this bridge site. It is divided into two spans, 170 meter span in the east side of the 76 meter height pylon, and 90 meter span between the pylon and abutment A2 at west end of this bridge. The superstructure is consisted with steel I-girder

and reinforced concrete deck. It is strong enough to resist seismic load as well as wind condition, though its own weight is relatively light. Since its two spans is not in equal length, the horizontal forces acting at ends of girder (cable-stayed bridge) is unbalance. To balance the extra horizontal force, an extra cable (each face) has been put in west side of pylon; and four high strength steel bars are used to connect abutment A2 as anchor. Meanwhile, a set of Pendulum is also built in abutment A2 to balance the vertical component of cable force at west end.

7. Remark

Designed to be an important landmark in Costa Rica, the Taiwan Friendship Bridge is designed with a 260 meters cable-stayed bridge that is orchestrated with a single pylon and four pairs of cables spanning asymmetrically on each side, forming a volcano-like landmark. The bridge spans over the deepest part of the Tempisque River with a height clearance of 10 meters. The approach bridge at the eastern side of the cable stayed bridge also adopting aesthetically crafted steel box girder composite bridge with a incremental launching construction method. Designed to accommodate the strong earthquake zones, the bridge is constructed as a turnkey project in a much shorter time than the originally planned 30 months period.

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