STABILITY ANALYSIS OF THE EFFECT OF SOIL SETTLEMENT ON A CABLE-STAYED BRIDGE IN THE MEKONG RIVER DELTA

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1. INTRODUCTION

The relationship between soil settlement and the stability of long-span cable-stayed bridges in the Mekong River Delta (in south western Vietnam) must be seriously assessed. However, there have been very few research studies on this topic, even though some highly destructive incidents have occurred, such as the incident involving the Can Tho Bridge, a cable-stayed bridge with the longest primary span in Southeast Asia.

Two numerical models were generated using existing details about the geometry, materials, and loads; one model was for the construction stage, and the other was for operation stage. Based on the collected data, an analysis of the soil reaction under the effects of loading was conducted. Difference combinations of pier and pylon displacements were applied to the simulated bridge models. Subsequently, the axial forces of the cables in each settlement case were calculated to confirm the stability of the bridge.

2. MATERIALS AND METHODS

The Can Tho Bridge (2010) crosses the Hau River (of the Mekong River System), connecting Can Tho City and Vinh Long province (in Southern Vietnam). The cable-stayed span arrangement is 40 + 40 + 270 + 550 + 270 + 400 + 40 m. Four approach bridges (two on each side) were considered, making the total length 1170 m (Figure 1).

Typically, the primary girder is a pre-stressed concrete box girder (26 m wide and 2.7 m high), that can accommodate four traffic lanes. For proper balance and cost saving, the girder was designed to have a 210m steel box girder in the middle of the 550m span. The pylons are inverted Y-shaped steel-reinforced concrete pylons (169 m high), as shown in Figure 1. The cables are arranged into a two-vertical-plane system.

The approach bridges, each 40 m in length, used ten 1,75m high super-T pre-stressed concrete beams, which are simply supported by reinforced concrete piers, height ranging from 22 to 25 m.

In this study, the cable elements are treated as plain truss elements with tensile axial forces and nonlinear material properties. During the construction and service stage, the cable stress changes from σ1 to σ2; the equivalent elastic modulus of cable can be obtained as (1).

$$\mathrm{E}_{eq} = \frac{E}{1 + \frac{(L_0\gamma)^2(\sigma_1+\sigma_2)}{24{\sigma_1}^2{\sigma_2}^2}E} \qquad (1)$$

The material data for the cable are shown in Table 1

Table 1. Properties of Cable

Tensile Strength	1770 N/mm^2
Yield Strength	0.9 Tensile Strength
0.8% proof stress	1370 N/mm^2
Young Modulus	195,000 MPa

The sample bridge was modeled using TDAP III software, based on the Finite Element Method. Two numerical models were generated during the analysis procedure; one is an incomplete bridge in a construction stage, just prior to the closure operation, and the other is the complete bridge during its operation stage. For the former model, only the north side of the bridge was considered because of symmetry. The primary girder is divided into 1010 two-dimensional elements (505 elements for the construction stage model). All nodes are fixed into a two-dimensional coordinate system.

The structure was analyzed under the Strength II Limit State – AASHTO. The bridge's dead loads and live loads are applied after geometric modeling. The reaction forces appearing at pylons and supporting piers for both cases are calculated.

Due to the settlement values obtained, forced displacements were increasingly applied to the pylons and piers for both simulated models. For each value set, several combinations of pier and pylon settlement were evaluated to highlight the greatest value of stress appearing in the cable system.

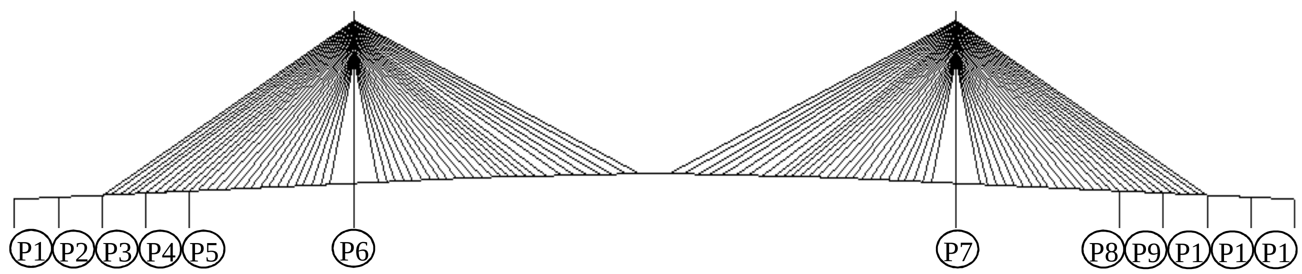

Figure 1. Elevation View of the Bridge

Keywords: Cable Stayed Bridge, Nonlinear Cable, Ground Settlement, Can Tho Bridge
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3. RESULTS AND DISCUSSION

Figure 2 shows the maximum stress appearing in the cable system under the effects of the pylon and supporting pier displacement during construction stage. There is little difference between the blue and red lines between the maximum and minimum vertical displacement, suggesting that the soil settlements do not significantly affect cable system. Surprisingly, the horizontal displacements play no part in the appearance of maximum stresses.

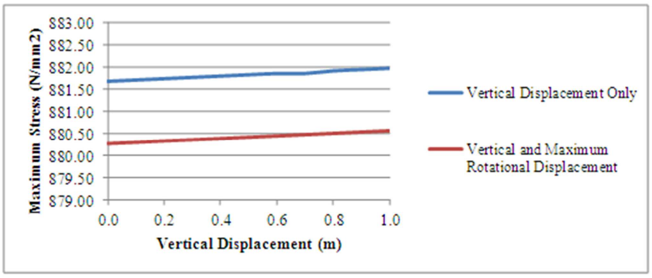

Figure 2. Maximum Tensile Stress in Cables System during Construction Stage

The case in which the vertical displacement reached its maximum value (approximately 1.0 m) was further investigated. Figure 3 shows the tensile stress in all cables, along with several combinations of soil settlement. The maximum tensile stress always appeared on the right side of the pylon. In the construction stage, the closure was not performed; therefore, the cables on this side were not affected by settlement.

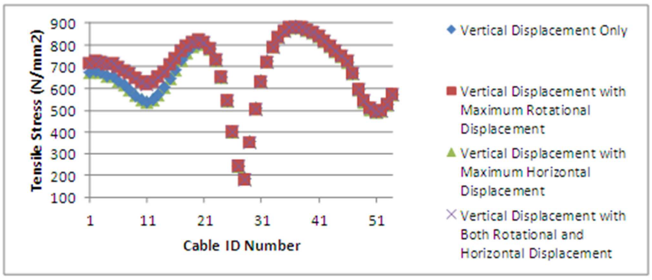

Figure 3. Tensile Stress in Cables System when ⊿v=100cm (Construction Stage)

In service stage, the effects of soil settlements are significant, as shown in Figure 4. As in the previous stage, the relationship between the vertical displacement and the maximum stress is quite linear; the more displacement that occurred, the greater stress on cables system. Figure 4 also shows that, the bridge is insecure when only encountering vertical displacements, with the maximum stresses reaching the tensile strength (1770 N/mm2) as the settlement reaches 1.2 m.

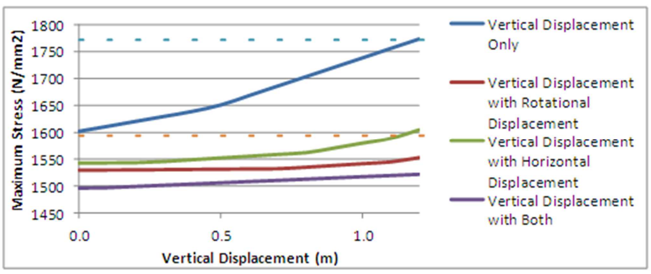

Figure 4. Maximum Tensile Stress in Cables System during Service Stage

The most dangerous situation occurred when the vertical displacement reached its maximum value of 120cm (shown in Figure 5). When the pylons only encountered vertical displacement, three cables exceeded their yield strengths, and one had its tensile stress exceed the tensile strength. However, when rotational and horizontal settlement occurred, those insecure stresses were neutralized. Consequently, every cable in the system was working below the yield strength limit.

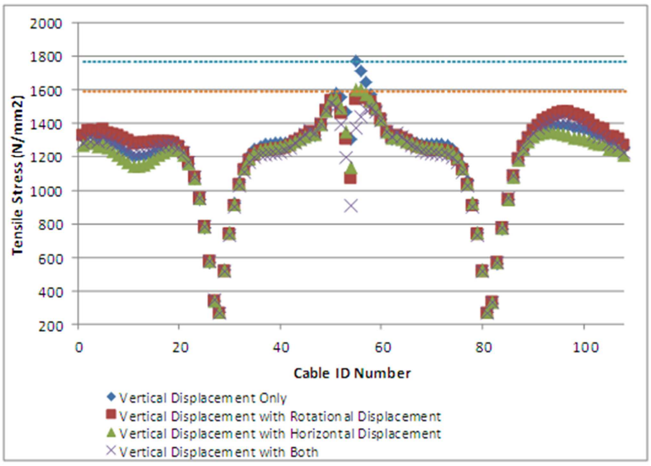

Figure 5. Tensile Stress in Cables System when ⊿v=120cm (Service Stage)

In general, soil settlement has a greater influence on the cable system during the service stage than during construction stage. More precisely, the vertical displacements of the piers must be cautiously monitored. However, in most cases, rotational and horizontal settlements rearrange stresses in the system and thus, increase the stability of the bridge.

4. CONCLUSIONS

This paper presented the relationship between the working condition of the cables (the most important part of a cable-stayed bridge) and the displacement of substructures. The calculated results suggest that during the service stage, vertical displacements have a major influence on the stability of a cable-stayed bridge. However, rotational and horizontal settlements produce unexpectedly beneficial effects that can neutralize the most critical working conditions of the cable system. Conversely, soil settlement does not play a significant role in the construction stage.

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