Reliability Analysis of Dominant Load Combination for Design of Concrete Pylon of Cable Supported Bridge

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ABSTRACT

Safety level in the design of the concrete pylon which is subject to both axial force and bending moment of a cable supported bridge is evaluated in terms of the reliability index. Over the height of the pylon, different combinations of the applied loads are governing the design of the sections. A brief presentation for the calibration of the ongoing project to develop a reliability-based design code for cable bridges are given in this paper. The major loads applied to the cable supported bridges such as dead load, live load, wind load and earthquake load are selected to form the design load combination. Several representative pylon sections such as rectangular, circular, octagonal and track shape both in solid and hollow are selected to be analyzed. First order reliability method is adopted to obtain the reliability index. The statistical properties of the material strength of concrete, reinforcing bar and cable and the dead load and live load are obtained from domestic data base. Different sets of load factors and resistance factors in the format of both material resistance factor and section force resistance factor are applied to obtain the reliability indexes and the results are compared. Numerical examples of a pylon of an existing cable bridge are used to obtain safety level for different sections along the height of the pylon.

1. INTRODUCTION

For the ongoing project for the development of a rational design specification for the long span cable supported bridges in Korea, calibration of the load factors and the resistance factors are being performed. The calibration is based on the probability and statistics of the load effect and the structural resistance. The statistical definition of the design load as well as the resistance of structure is required before it is multiplied to the appropriate load and resistance factors.

Some of the major loads in designing the cable bridges are dead load, live load, wind load and earthquake load. The statistical properties of these major loads are required if the safety level of the design is to be presented in terms of probabilistic index. The statistical data of the dead load, the traffic live load or the wind could be collected from various sources such as the construction report, the truck weighing-in-motion data or the report from the climate bureau. On the contrary, the statistical properties of the earthquake are not easy to define by analyzing available data, especially in those areas where the earthquake is not common. In that case, a proper determination of the properties is required through past design experience or professional judgment.

Material strength is an important design parameter to determine the statistical properties of the structural resistance. In order to calibrate the domestic design code, it is necessary to collect and analyze the construction material data to be used in structural design.

2. LOAD COMBINATION AND RESISTANCE FACTOR FORMAT

Current structural design codes adopt load and resistance factor system in providing certain amount of safety. The values of the load factors depend on the characteristic values, the statistical properties of the loads and the past experience as well as the level of safety for the design. When several loads are combined to form a design load combination, the combination factors which are less than one are applied to reduce the amount of the factored loads so that the probability of simultaneous occurrence of the combined loads are somewhat similar to that of the single characteristic load.

The load factors for the live load, wind load and earthquake load combinations for the current Korea Bridge Design Code (KBDC) and the proposed design code are shown in Table 1.
In Table 1, D, L, W, EQ, CS, T, SE stand for dead, live, wind, earthquake, creep & shrinkage, temperature and support settlement, respectively.

Also, the values and the formats of the resistance factors depend on the similar things as in the case of loads. Design of concrete members in the proposed specification adopts the material resistance factor format. The current design code of concrete structure in Korea uses the member resistance factor format in which the resistance factor is defined with respect to the tensile strain ε_t of the external reinforcement. As shown in Fig. 1, the resistance factor is 0.85 in the tensile failure region and 0.65 in the compression failure region. Equivalent member resistance factor for ε_t is defined as in Eq. (1) and is compared with the member resistance factor in Fig. 1.

$$\phi_{equi} = \frac{R_d}{R_n} = \frac{R\left(\phi_i X_{k,\ i}\right)}{R_n} \tag{1}$$

Table 1. Load combination for KBDC and the proposed specification

	Live Load	Wind	Earthquake
KBDC	1.30D + 2.15L	1.3D + 1.3W	1.0D + 1.0E
Proposed Spec.	1.25D + 1.80L	1.25D + 1.4W 1.25D + 1.4W + 0.5/1.2(CS + T) + 1.0SE	1.0D + 1.0E

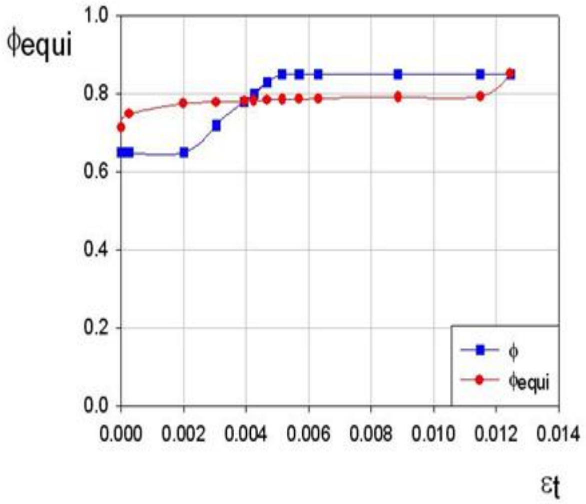

Fig. 1. Comparison of the equivalent resistance factor with the member resistance factor

3. RELIABILITY ANALYSIS OF PYLON

Structural analysis is performed for a cable stayed bridge with 540m center span length. Load effects on the pylon are obtained by applying the load combination as described in Table 1. The schematic figure for the pylon is shown on the left in Fig. 2. The design of the lowest section of the pylon, which is designated as LL-BOT in Fig. 1 which stands for the bottom of the lower level, is governed by the wind load combination. The design of the section UL-BOT which stands for the bottom of the upper level of the pylon is governed by the earthquake load combination.

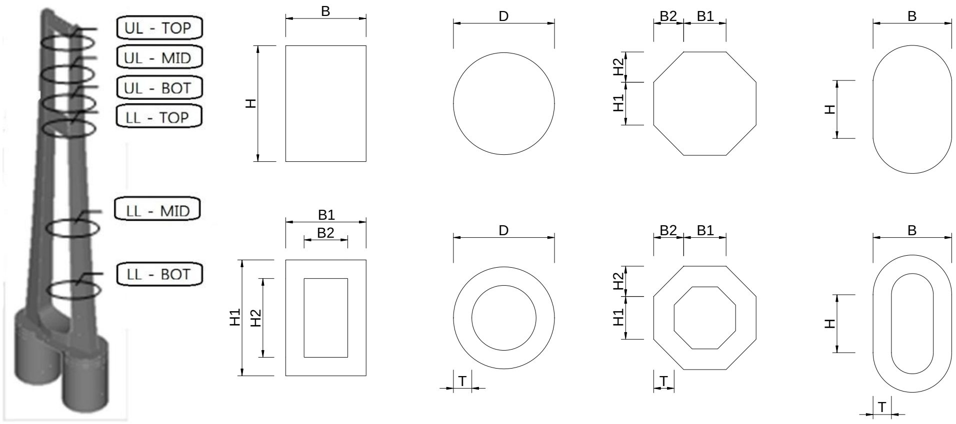

Fig. 2. Section types of pylon of cable supported bridge

A computer program is written to simulate the statistical properties of the strength of the pylon section and the typical section types are shown in Fig. 2. The strength P-M diagram for a selected section is calculated as shown in Fig. 3 and the statistical properties of the strength are obtained. The material strength data of concrete, steel reinforcement are collected from domestic construction sites and the statistical properties are calculated and are used in the simulation.

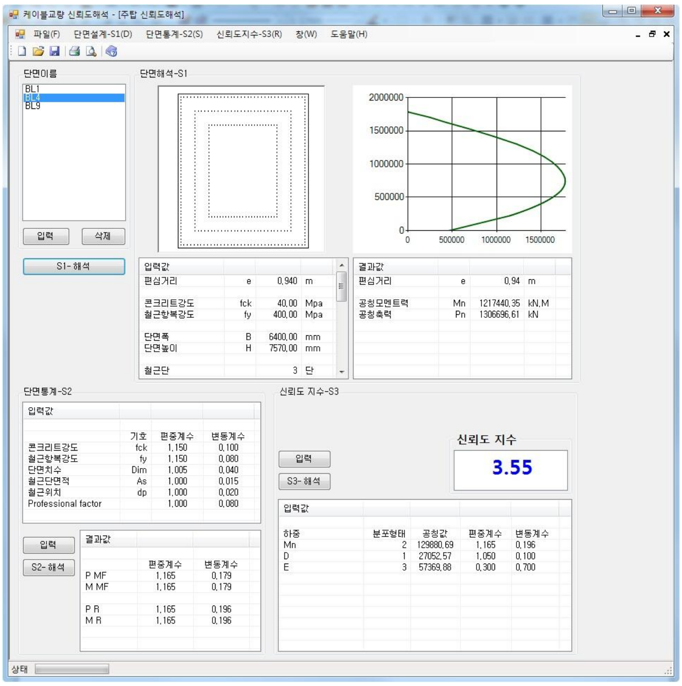

Fig. 3. Example of pylon reliability calculation

The same values of the bias factor and the coefficient of variation (COV) for loads as used in AASHTO LRFD calibration are selected in the reliability calculation. The bias factor and the COV is 1.05 and 0.10 for the dead load, 0.875, 0.20 for the wind, and 0.30, 0.70 for the earthquake, respectively.

The limit state functions for the live load, the wind load and the earthquake load are as shown in Eq. (2).

$$\begin{aligned} g &= R - D - L \\ g &= R - D - W \\ g &= R - D - W - CS - T - SE \\ g &= R - D - E \end{aligned} \tag{2}$$

Reliability indexes are calculated using the first order reliability method and the results are shown in Fig. 4 for the live load combination and in Fig. 5 for the wind load combination. Fig. 4 shows that the reliability index β for the live load combination is the largest for the axial force and the values are between 5 and 6. β is decreased for the transition region. β is the smallest for the flexure and the values are around 4.

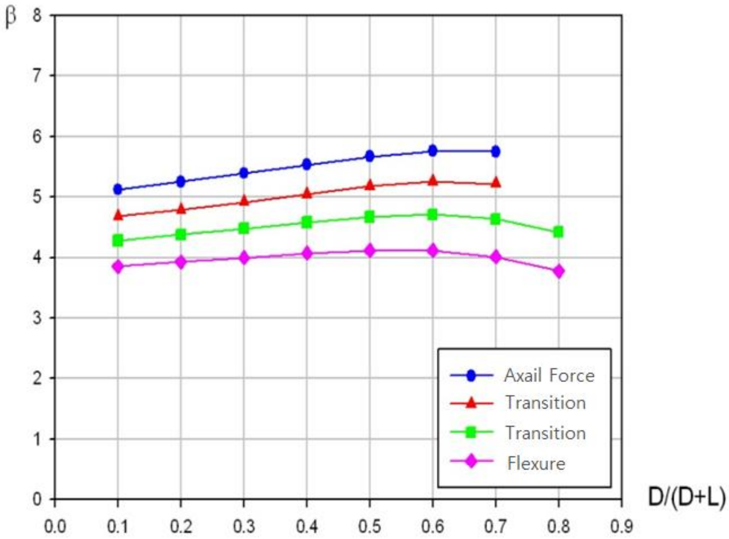

Fig. 4. Reliability index for live load combination

Fig. 5 shows the reliability index β for the wind load combination and β is about 3.5 for the current KBDC load factors and it increases slightly for the propose wind load combinations as the load factor for wind is slightly increased in the proposed code. The reliability index β for the earthquake load combination yields 3.55 using the statistical properties as assumed earlier.

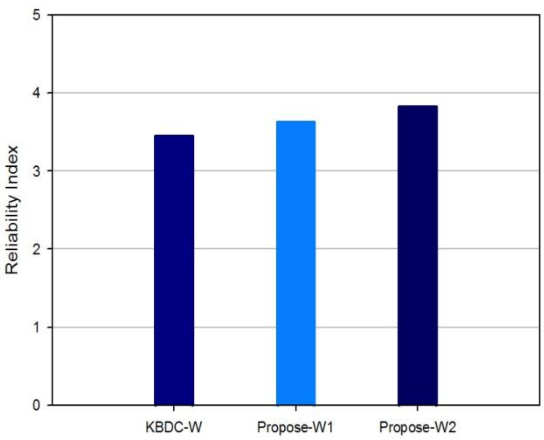

Fig. 5. Reliability index for wind load combination

CONCLUSION

Calibration of the load and resistance factors are performed for a reliability-based design specification of cable supported bridges under development in Korea. In this study, the reliability analysis procedure for the concrete pylon is briefly presented with examples. The statistical properties for the analysis are obtained from domestic field data, references and professional judgment. Further efforts are being made to define the load models with respect to probabilistic concept. Also, the reliability levels for the main members such as the stiffened girder and the cables are being investigated.

ACKNOWLEDGEMENT

This research was supported by the grant from the Ministry of Land, Transport and Maritime of Korean government through the Core Research Institute at Seoul National University for Core Engineering Technology Development of Super Long Span Bridge R&D Center.

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