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Dead Load Analysis of Cable-Stayed Bridge

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Abstract. For cable-stayed bridges the cable forces are an important factor in the design process. By analyzing a simple structural system, the procedure using the analysis program MiDAS is illustrated. The generation of the model for the finished dead stage analysis is illustrated in detail, including the boundary conditions and variations in loading. The optimization method of unknown load factor is used to determine the cable forces to achieve an ideal state. The ideal cable forces are established and a construction stage analysis is performed. The maximum cable forces are proved to be in the allowable limits. The results obtained revealed that the method presented indeed leads to optimal structural performance for the cable-stayed bridge in particular, and might be a useful reference for the design of other similar bridges.

Keywords: dead load, cable-stayed bridge, unknown load factor

1. Introduction

Cable-stayed bridges are structural systems which are effectively composed of cables, the main girder and towers. This bridge form has a fine-looking appearance and fits in with most surrounding environments [1]. The structural systems can be varied by changing the tower shapes and the cable arrangements [2]. Up to a span length of 1000 metres, the cable stayed system is considered as an economical solution [3]. For cable-stayed bridges the cable forces are an important factor in the design process [4].

In this paper the computer program MiDAS is used to model and analyse the examples. The bending moments in the main girder and the pylon are minimized by the chosen cable forces. Structural analysis programmes apply optimisation methods to minimize the internal forces in the calculation of the ideal cable forces. The calculation considers user defined restrictions for forces or moments, stresses and displacements; the reasonable results are obtained.

2. Bridge Description

The Xing Jia bridge under consideration is a 3-span composite cable-stayed bridge with an overall length of 420m (100m+ 220m+ 100m). The deck is 15.6 m wide. It comprises two longitudinal steel girders, approximately 2.5 m deep, transverse steel trusses at 3 m spacing and a reinforced concrete slab between 200 and 350 mm in depth. The deck of each cable-stayed cantilever section is supported by a total of 10 cables, with 10 cables arranged in each semi-fan configuration on each side of the pylon, in two planes, either side of the bridge deck. Each reinforced concrete pylon comprises two towers and two crossbeams, the lower one supporting the deck. During construction, longitudinal motion of the deck was restrained at the pylon bearing to resist temporary out-of-balance. Fig. 1 shows a schematic representation of the bridge with elevation view. A photograph of the completed Xing Jia cable-stayed bridge is shown in Fig. 2.

3. Finite Element Models

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The structure was modelled as a composition of substructures as follows:

A steel-trusses 'deck girder' with diaphragms, is modeled with conventional three dimensional (3-D) beam elements, forms a 'spine' for the deck. To achieve this, all the bending, torsional and inertial properties of the steel trusses-deck composite girder are equivalent to that of the beam.

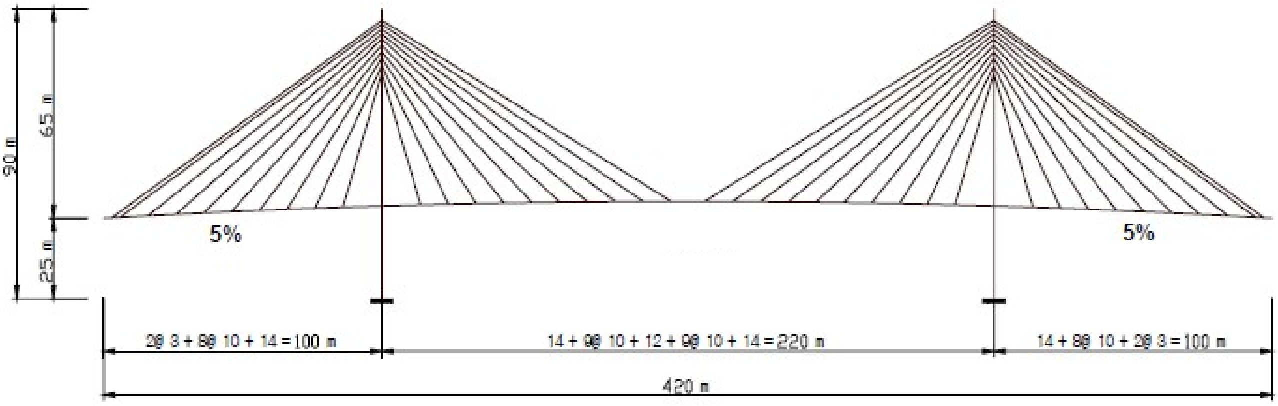

Fig.1 Schematic plan of Xing Jia bridg

Fig.2 Xing Jia bridg

- Pylon, tower and cross beams are modeled as beam elements while foundation restraints are modeled as 3-D beam elements. The final values for the beam elements representing the foundations are significantly higher than the original values used by the consultants, and essentially fix the support points in translation.
- A system of 'pseudo-beams' and beam elements models the notional traffic lanes, all having zero density and relatively large stiffness. The function of these elements in the static load is to transfer

vehicle loading to the spine beam, but these elements also help to visualize the static behavior of the deck.

- Concrete with elastic modulus 36 GPa was assumed for the deck girder and pylon, with 1% of the nominal 36 GPa stiffness used for pseudo-beams. The cables were assumed to have moduli in the range 192–195 GPa. Fig. 3 shows the finite element model incorporating all the above elements. Boundary conditions are indicated as green highlight.
- The cable tension is initially expected to have a significant effect on the bridge mechanical properties via geometric stiffness effects due to the cable tensions. For the computer code used (Midas Civil 6.7.1) these tensions have to be predetermined in a prior static analysis and then carried over into the global stiffness matrix for optimization analysis. The prior static analysis could begin with a neutral unloaded condition and impose a gravity load but this would result in initial bending stresses in the deck and low cable tensions. Instead, initial tensile strains estimated from the design tensions were set in the cables with the aim of producing neutral deck stresses and correct cable tensions. In fact it was necessary to iterate with different initial strains to generate close approximations to the design tension values in the cables for the optimization analysis.
- For static systems, linear and non-linear analyses can be performed by using truss and cable elements. Geometric non-linearities can be considered by including P-delta effects in the calculation or by performing a large displacement analysis.

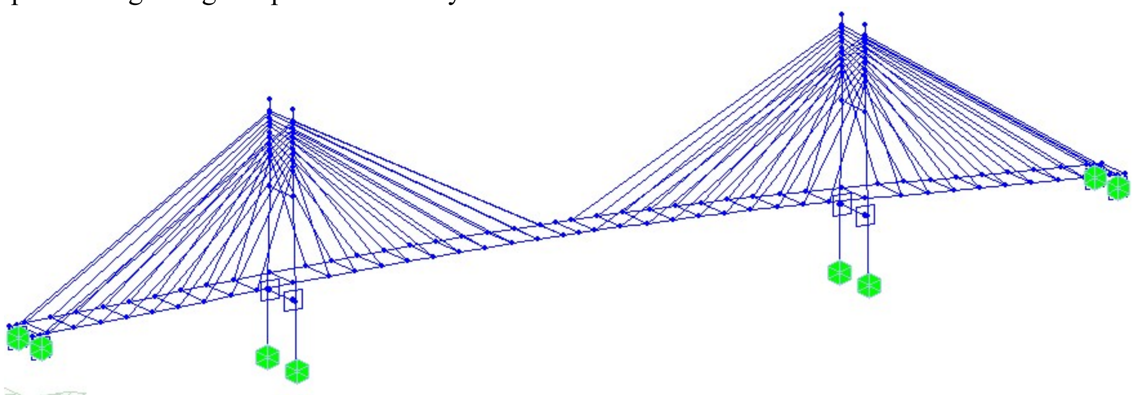

Fig.3 The finite element model of Xing Jia bridg

4. Unknown Load Factor Optimization

The permanent state of stress in a cable-stayed bridge subject to its dead load is determined by the tension forces in the cable stays. They are introduced to reduce the bending moments in the main girder and to support the reactions in the bridge structure. The cable tension should be chosen in a way that bending moments in the girders and the pylons are eliminated or at least reduced as much as possible. Hence, the deck and pylon would be mainly under compression under the dead load.

The analysis program MiDAS provides the unknown load factor function, which is based on an optimization technique. It can be used to calculate the load factors that satisfy specific boundary conditions (constrains) defined for a system.

Initial pre-stressing forces can be calculated through optimizing the equilibrium state. The calculation of the ideal cable prestressing forces by the optimization is restricted to the linear analysis as the different loadings are superposed. The initial cable pre-stressing forces are obtained by the unknown load factor function and the initial equilibrium state analysis of a completed cable-stayed bridge.

4.1. Unknown Load Factor

The first step of analyzing a cable-stayed bridge, in order to perform a construction stage analysis, is to evaluate the ideal cable forces for the final structure under it’s self-weight. The general procedure of calculating these ideal cable forces by the unknown load factor function in MiDAS is outlined in Fig. 4. The function allows the determination of superposition factors for previously calculated load cases to obtain a prescribed state in the structure by combining those load cases. As far as a solution for realizing the user defined conditions exists, the factors will be calculated.

To determine the unknown load factors for each cable stay to achieve an ideal state, a unit pretension load is applied for each cable. Performing a linear analysis, the program computes the influence on the structure due to each unit tension load. In the unknown load data the unit load cases are then defined as an unknown load. Furthermore, the structural restrictions for e.g. moment or vertical displacement values, which are to be realized through the load factors in the combined load case, must be defined. A continuous beam condition for the main girder can be achieved.

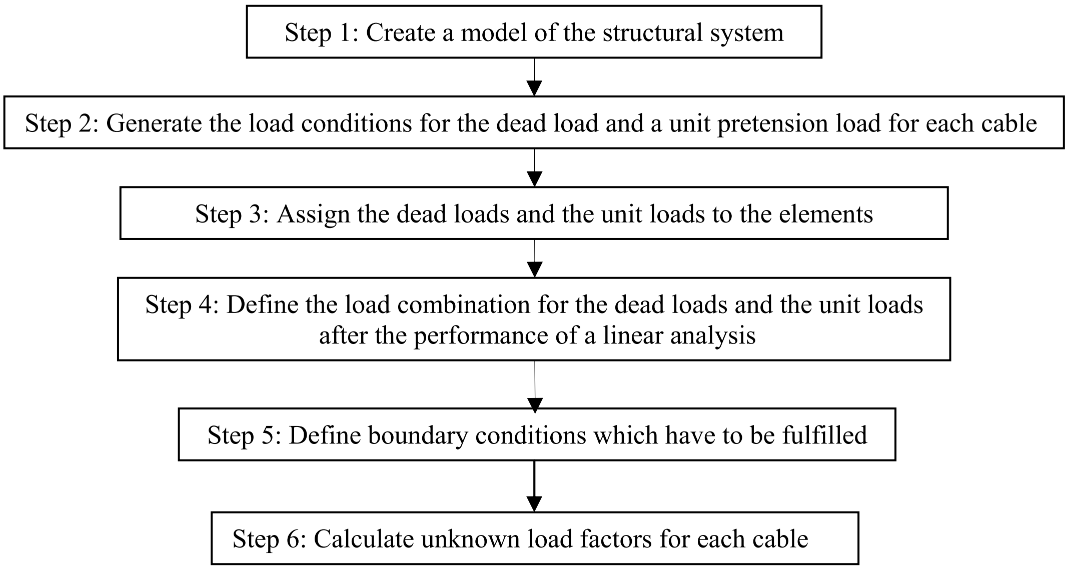

Fig.4 Flowchart for cable initial prestress calculation

4.2. Cable Forces

The calculated cable forces for each construction stage are used as external prestress loads for the forward analysis. In order to fulfil the defined restrictions, the load factors are calculated. Fig.5 illustrates the result table given by MiDAS. For this table, the factors for Cable 1, 2 and 3 are 129.96, 123.75 and 108.35 respectively. The values can be found in Fig.5 in the second column.

With an optimized adjustment of the cable forces, it is possible to achieve an "ideal state", at which the girder and the pylon are compressed with little bending only. The "ideal state" of a cable-stayed bridge is associated with the minimized total bending energy accumulated along the girder. This results in a possible design of slender decks. The materials for the deck and the pylons can be efficiently utilized. Moreover, in case of concrete decks, it has dominant influence on the creeping behaviour. Fig.6 shows the resulting force distribution including the factors for the tension forces in the cable stays 1 to 20. The maximum cable force is 0.237 GPa at the beginning of the main girder, which is within the allowable range of the tension strength limit of the tendon. The maximum moment at the top of the pylon is now 356 tonfm and -521 tonfm at the bottom. The maximum moment in the girder is -82.56 tonfm at the anchorage of the beginning stays and -411 tonfm at the pylon. All of the moments are still within an acceptable range.

Fig.5 Results of the unknown load factor calculation

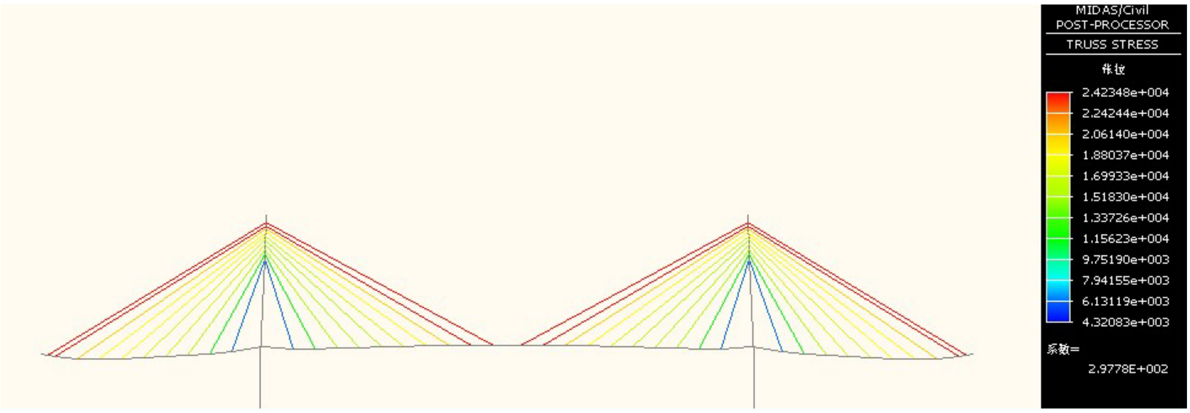

Fig.6 Cable forces [tonf/m^2]

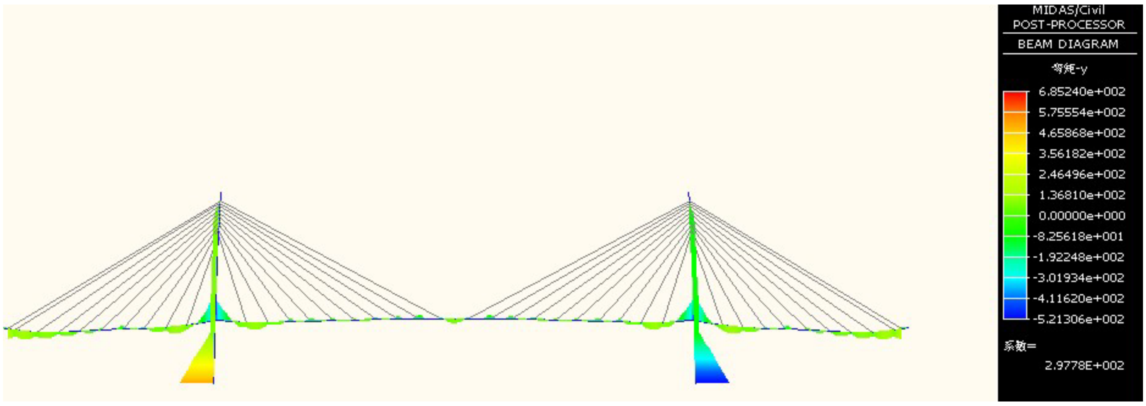

Fig.7 Moment distribution [tonfm]

5. Conclusions

- A detailed dead load stage analysis is performed using the analysis program MiDAS. The main issues relating to the modeling of the structure are outlined.
- To develop the "ideal state" system by an appropriate cable pre-stressing, unknown load factors are applied in the analysis. With the restriction of the vertical displacement and moment, a continuous beam condition for the main girder can be achieved.
- The ideal cable forces are determined to achieve an optimal structural performance due to its permanent loads.
- For all dead load stages, the minimal and the maximal moments are controlled to be within an allowable range.

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