Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 11, No. 3, 2024

Mechanical Properties and Design Methods of Pedestrian Suspension Bridges Research Status Report

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Abstract: As the quality of life improves, travelling becomes a hotspot of life, and pedestrian suspension bridges, as a new highlight of tourism, are both convenient and ornamental. The structural system arrangement is crucial to the performance of suspension bridges. Based on the computational theory of suspension bridges, this study explores the influence of the arrangement on the static and dynamic performance and proposes an optimisation scheme. By comparing different design methods, the design process is simplified and the scope of application is clarified. This result will provide an important reference for the future design of suspension bridges and help the development of tourism.

Keywords: Suspension Bridge; Static and Dynamic Performance; Static Dynamic Theory.

1. Introduction

Pedestrian suspension bridge, as a rope as the main load-bearing structural system, its deck is narrower, the bridge body is more flexible, the degree of structural geometric nonlinearity is higher, unlike other forms of bridges, for the structural calculations and the degree of dependence on the degree of line is very high. For the design of pedestrian suspension bridges, reference can only be made according to this specification. Due to the loads, boundary conditions, component size and other differences, making its target is not strong, the reference significance is limited. Therefore, the thesis through the pedestrian suspension of different structural system parameters on its mechanical properties and pedestrian suspension bridge calculation theory of the simplification of the method of research, so that it is for pedestrian suspension bridge in the layout, design, calculation of a certain reference and help.

2. Current Status of Domestic and International Research on the Calculation Theory of Suspension Bridges

2.1. Elastinism

The theory of elasticity is the first theory of structural analysis of suspension bridges began, this theory in the use of suspension bridges up to more than a century. In the previous suspension bridge is not any mechanical analysis methods, are based on empirical approximation of construction, in 1823, France's Navier [1] published a non-stiffened suspension bridge calculation theory, followed by Rankine [2,3] and other theoretical development, and finally by the D.B. steilunan [4,5] collated into the standard elasticity of the later used form of theory. The theory assumes that the length of the suspension cable does not elongate due to the live load, the vertical deflection at each point along the main cable is the same as the deflection at each corresponding point of the stiffened beam, and it is considered that the main cable carries the self-weight and all the constant loads of the bridge deck, and its geometry is a quadratic parabola, which does not change due to the subsequent changes in the external loads acting on the bridge deck. This makes the suspension bridge a simple combined system of main cables and stiffened beams with linear elastic properties, and the principle of superposition applies to it.

The theory of elasticity does not take into account the contribution of the constant load to the vertical stiffness, nor does it consider the nonlinear effects of displacement, and it is based on the calculations of the theory of small deformations to solve the superstatic structure. Before the widespread use of computers, for different forms of suspension bridges (simply supported or continuous), scholars have established the calculation formulae of the theory of elasticity, and now it can be calculated by the finite element linear analysis programme of linear elasticity. Through the comparative analysis of the elasticity theory of the analysis results are on the safe side, but the use of this theory for the design will cause a serious waste of materials. At the same time, when the span increases to a certain degree, the calculation results of the elasticity theory will be seriously deviated from the actual, cannot reasonably adopt the calculation.

2.2. The Theory of Deflection

In 1928, Timoshenko used the trigonometric series form of the deflection function to solve the basic differential equation of the deflection theory, Godard [6] took into account the characteristics of suspension bridges with a small live constant, so they omitted the part of the resistance caused by the live load, Hpv, i.e., Hpv in the basic differential equation, and proposed a simple linear deflection theory. Nowadays, there are still many scholars who propose various different solutions to the differential equations of the deflection theory, such as H. Ohshima et al. solved the base differential equation by Laplace transformation; JenningsA. proposed the gravity stiffness method in 1980 [7], which in essence also ignores the effect of the bending stiffness of stiffened beams, i.e., ignoring the base differential equation in the EId4v/dx4 term, which leads to an approximate solution.

2.3. Finite Displacements

The concept and method of finite element analysis was introduced in 1943 by Courant in his study of torsion [11]. Along with the advent of digital computers, the direct stiffness method, as it is known today, was introduced by Turner, Clough and Martin et al. in their paper in 1953.After a paper on planar elasticity problems by Clough in 1960 made engineers aware of the efficacy of the finite element discretisation method [8], and since then, with the development of computers and software technology Since then, with the development of computer and software technology, the finite element method has also developed rapidly, and become a powerful tool for engineers to solve engineering problems. 1966 Brotton first published a general method of structural analysis of suspension bridges to solve the matrix displacement method [9], this method is based on the direct stiffness method, consider the main cable due to the axial force of the constant load on the structural equilibrium of the large-displacement effect. From then on, the analysis of suspension bridges has stepped into the era of finite displacement theory. At the same time, Poskitt, also published their research results.

who specialised in the calculation of vertical suspension rods for suspension bridges, concluded that the axial force of stiffened beams and the effect on bending is minimal. Saafan's method is a generalised finite element analysis method, which takes into account the second-order effects of the initial moments and moment-shear interactions to derive the tangent stiffness matrix, and the effect of the axial force on the bending is considered by means of the stabilisation coefficients method. The system of nonlinear equations is solved by Newton-Raphson iterative method in incremental form. Tezcan method is the same as Brotton in principle, which is adapted and improved on the basis of the system of nonlinear equations solved by direct iterative method with the introduction of attenuation coefficients.

2.4. Calculation Theory of Suspension Bridge Sections

Suspension bridge due to the main cable to find the type of the problem, its non-linear degree is high, the main cable each cable segment and equilibrium equations are established in the deformation of the position after the deformation, therefore, in the for each cable segment division and cable segment approximation simulation of the different, its suspension cable segmentation is divided into four theories, respectively, the traditional parabolic theory, the segmented parabolic theory, the segmented straight line theory, segmented suspension chain line theory. Its analytical method according to the division of cable segment approximation degree is different, and the formation of different theories, for these different methods, Zhou New Year in his book, ‘Engineering cableways and flexible suspension bridges For these different methods, Zhou Xinxin in his book ‘Engineering Ropeways and Flexible Suspension Bridges derives the principles and approximations of the different methods, and shows the application of the different theories under different conditions.

For these four methods of solving, the segmented suspension chain line theory has the highest accuracy, the most consistent with the actual situation, and the most accurate calculation results, while the segmented parabolic, segmented straight line theory is more inferior, and the traditional parabolic theory has the worst accuracy. Due to the use of segmental chain lines in the calculation of engineering, its formula through the Taylor series expansion, respectively, after the omission of the higher-order terms and can only get an approximate solution. The error is reliable for a certain bridge length. However, due to the use of segmental suspension chain line calculation process, solving the main cable line shape needs to be nonlinear iteration, iteration method has a direct impact on the size of the workload and the speed of the solution. At present, the main analysis methods are analytical method and finite element method, and its iterative method can be categorised as Newton-Raphson method and influence matrix method, through which the iterative convergence of the cable segment equations can be ensured to meet the computational needs.

2.5. Theoretical Development of Suspension Bridge Dynamic Performance Analysis

The development and study of the self-vibration properties of suspension bridges is the basis for the study of the dynamic behaviour of suspension bridges, had made a very detailed analysis of the static dynamic performance of suspension cables, as well as a detailed review of the previous studies. The detailed study of the vibration theory of suspension bridges, on the other hand, has been taken into account by specialists since the wind-damage accident of the Old Tacoma Suspension Bridge in the autumn of 1940.Its determination and understanding of the self-oscillating properties, especially for the seismic and wind resistance of pedestrian suspension bridges, as well as the comfort of people walking on them, play a very important role.

At present, to determine the vibration type and frequency of suspension bridges, the methods are roughly divided into three categories.

(1) Classical analysis method

This type of method is derived from Hamilon's principle as a distributed parameter system function form of partial differential equations for a method of analysis, published by Bleich in 1950, ‘the mathematical theory of vibration of suspension bridges, on which there is a more detailed description.

(2) Approximate methods and empirical formulas

Mainly based on the energy principle, the Rayleigh-Riz method for the approximate solution of the method, which is used to calculate the higher-order frequency will have a certain error, but the calculation of the lower-order frequency is reliable, so in as a study of the lower-order frequency and the process of approximate calculation of suspension bridges, this method is of some value.

(3) Numerical method

Numerical method refers to the structure as a discrete parameter multi-degree-of-freedom system with numerical approximation method and with the help of a computer to find the vibration pattern and frequency method, this type of method is accompanied by the development of computers, computational mathematics and computational mechanics. Yamada established a numerical method for determining the mode and frequency of vertical and longitudinal vibrations of suspension bridges as a discrete parameter spring-mass system with multiple degrees of freedom.

3. Research Objective

(1) Through the analysis of the static parameters of the structure, to determine the influence of the arrangement of the main structure of the pedestrian suspension bridge on the internal force of the bridge, and to provide a more reasonable arrangement scheme for the future structural arrangement of this type of structural system.

(2) Through the parameter analysis of the dynamic structure, the relationship between the structural arrangement and its self-resonance frequency and the internal force under earthquake can be obtained by changing the structural arrangement for bridges with different demands, so as to provide a certain reference for the determination of the scheme of bridges with different demands in the future design.

(3) Through the research and analysis of the calculation theory of pedestrian suspension bridges and theoretical comparisons, a more suitable calculation theory is identified, and a simple calculation method on such theory is summarised to provide certain technical guidance for the design of pedestrian suspension bridges.

4. Implementation Programme

4.1. Research Methods and Measures

(1) For the parametric analysis of pedestrian suspension bridge, through the finite element analysis software midas civil on a 200m long suspension bridge for parametric analysis, by changing its parameter conditions in the empty cable as well as under the state of the bridge force state, as well as dynamic performance.

(2) For the theoretical analysis of pedestrian suspension bridge, combined with the existing theory of suspension bridge, through the study of the calculation of deflection theory and the simplification process, will be applied to the structural system of pedestrian suspension bridge.

(3) Combining the design process of the pedestrian suspension bridge and the field inspection during the construction process of the suspension bridge, for the problems and errors during the construction as well as the results of the bridge inspection after the bridge is completed, the computational theory is compared and analyzed with the inspection result report and the finite element theory, to come up with a reasonable computational simplification method.

(4) Collate the parameter analysis results and calculation theory results to provide certain suggestions and help for the design of future pedestrian suspension bridges.

4.2. Ways to Solve the Problem

(1) Consult foreign literature and similar design projects in China, and at the same time, communicate with the construction side of the pedestrian suspension bridge and the evaluation and design experts of the suspension bridge, and combine their years of experience in construction with the theory of the existing suspension structure and relevant literature to make an all-around analysis of the bridge.

(2) For some of the construction sites with good traffic conditions, make field visits, communicate with experienced construction parties, and at the same time, use the network, take photos and records of the construction works, so as to provide a better practical basis for the research of design methods and mechanical properties.

(3) Use the existing computer technology to program the calculation formula to solve the tedious calculation process for the comparative analysis of suspension bridges.

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