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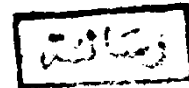
DYNAMIC RESPONSE OF CABLE STAYED BRIDGES

BY

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A THESIS



SUBMITTED IN FULFILLMENT FOR THE REQUIREMENTS
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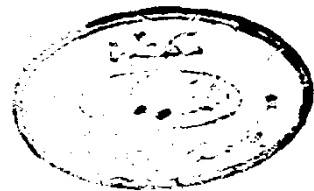
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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Doctor of Philosophy in Civil Engineering (Structural).

The work included in this thesis was carried out by the author under the channel system between the Department of Structural Engineering, Ain Shams University and the Polytechnic of Central London, from 1984 to 1988.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

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SUMMARY

This thesis is an investigation of the static and dynamic response of three dimensional cable stayed bridges. Theoretical, experimental and numerical studies were carried out for this purpose.

Theoretically, the research work is divided into three parts:

Firstly, a numerical procedure for the static analysis of highly non-linear three dimensional cable and cable skeletal structures, based on minimization of the total potential work, has been extended to include the instability effects caused by axial loads. This was achieved through an iterative process using the conjugate gradients method in which the stability and bowing functions are included and updated using either a Newton-Raphson iterations or a linearized incremental approach.

Secondly, the non-linear dynamic response of framed structures has been achieved using the integration in time domain. The complete theory, which is based on minimization of the total potential work, has been developed in terms of three well known set of numerical integration equations: the linear change of acceleration equations, the Newmark equations and the Wilson- θ equations.

Thirdly, an analytical procedure is developed for simulating artificial accelerograms to be used in practical design. The procedure is based on the autoregressive model and the mathematical equations derived for the simulations possess a time variation in the mean square amplitude as well as variation in the frequency content. The validity of the procedure has been successfully demonstrated against nine earthquake records. Further, an extensive study has been conducted to identify and estimate the main factors characterizing the autoregressive model for simulating earthquakes with different characteristics.

Experimentally, a 20 m model for box girder cable stayed bridge was designed and constructed in order to verify the static and dynamic theories and the numerical modelling of the bridge and to study the static and dynamic behaviour of cable stayed bridges. In order to study the damping characteristics of the model, the response of the structure to sinusoidal and sudden release of load was investigated. The damping ratios were measured in different ways and then used for constructing a damping matrix using Rayleigh damping to prove the validity of the theory. Finally, the experimental results are compared with the theoretical predictions.

Numerically, the static and dynamic behaviour of cable stayed bridges and their behaviour when subjected to earthquake loading have been investigated. This study can be divided into two parts:

The first part, the stability of cable stayed bridges as three dimensional structure is examined in order to estimate the factor of safety against buckling. The effect of varying six parameters were studied by using two different methods: The stability finite deflection theory and the dynamic stiffness matrix. In addition, the stability of three existing cable stayed bridges is examined together with a comparative study illustrating the influence of the tower shape on the lateral stability of the North bridge.

The second part, the effect of earthquake loading on the dynamic behaviour of cable stayed bridges has been investigated as three dimensional structure. Three methods for dynamic analysis: normal mode superposition, response spectrum and step by step integration methods have been described. The validity of these methods for predicting the dynamic response of cable stayed bridges due to earthquakes are examined together with the effect of the following three parameters: the influence of damping, tower shape and the effect of single and multicomponent earthquakes.

A summary of the work carried out is given together with general conclusions and suggestions for future work.

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CHAPTER 1

INTRODUCTION

1.1. HISTORY AND INVENTORY OF CABLE-STAYED BRIDGES

The idea of supporting a bridge deck by inclined elements sufficiently close to each other: chains, rods or cables is not new. The first application was probably in 1784 when a German carpenter, Immanuel Löscher (1,2,3) in Friboury designed a timber bridge of 32 m span consisting of timber stays attached to a timber tower.

The technical literature then indicates a void in the use of stayed bridges until 1817, when two British engineers, Redpath and Brown, built the King's Meadow foot bridge, which has an approximate span of 34 m, using inclined wire cables attached to a cast iron tower. Around 1821, the French architect, Poyet, suggested supporting the beams from rather tall towers with wrought iron bars. In this system, he proposed fan shaped arrangement of stays anchorage at the top of the tower.

It is possible that stayed bridges would have become a more usual form of construction had it not been for the bad publicity resulting from the collapse of two bridges. One was the 79 m pedestrian bridge crossing the Tweed River near Dryburgh-Abbey, England, which collapsed in 1818 as a result of the chain stays breaking due to wind oscillations (4). The other bridge that is credited with delaying the use of cable-stayed bridges was erected across the Saale River at Nienburg, Germany, with a 78 m span. However, after one year, the bridge collapsed under a crowd of people because of chain-stay failures.

It was noted that in many cases these early cable-stayed bridges actually possessed structural defects which led to their collapse. This was mainly due to the difficulty of calculating the stresses and displacements of the structure and also to the lack of understanding the actual behaviour of the bridge.

Despite adverse criticisms of the stayed bridge, a few more bridges were built shortly after the collapse of the bridges in England and Germany. Around 1840, an English man, used chain stays in a parallel configuration resembling harp strings. He maintained the parallel spacing of the main stays by using a closely subsystem anchored to the deck and perpendicular to the principle load carrying cables.

The long period of absence of stayed bridges during the 18th and 19th centuries can be attributed to the inability in analysis such structures. The lack of understanding of the behaviour of the stayed systems and the methods for analysing highly indeterminate systems appears to have been the major drawbacks to the rapid development of the concept. Not only was the theory lacking but the materials of the period for constructing the stays were not suitable. The steel used for round bars and chains of various types at the time exhibit low strengths and could not be pretensioned to avoid slackness resulting from unsymmetrical loading.

In 1938, a German engineer, Dischinger, appears to have rediscovered the stayed bridge while he was trying to design a suspension bridge with a 753 m span over the River Elbe near Hamburg, Germany, that would accommodate a two tracks rail road. To reduce the deflections under heavy loading, he introduced highly stressed stay cables. Dischinger published his results in 1949 and immediately several cable-stayed bridges were proposed at competitions for reconstructing bridges across the River Rhine in Germany.

In 1952, Leonhardt designed a cable-stayed bridge across the Rhine River in Düsseldorf, that was built in 1958. At the same time, the German Firm Demag in collaboration with Dischinger designed the Strömsund bridge in Sweden. It was erected in 1955 and was the first modern cable stayed bridge. After these two cable-stayed bridges had proved to be simple to erect, economical and very stiff under the traffic loads, the way was open for further successful applications. The new system quickly become popular in Germany and later in several other countries.

1.2. THE BASIC DESIGN CONCEPT OF EXISTING CABLE-STAYED BRIDGES

A survey and study of existing bridges reveals useful data with respect to the general suitability of a particular type of bridges and the geometrical proportions that are most suited for any particular case. In the following, many of the existing cable-stayed bridges are examined to identify major constructional and design features. An extensive survey dealing with the analysis, design, fabrication and erection of these bridges can be found in references (4-60).

1.2.1. Cable Arrangements

A wide variety of stay geometry has been employed in the construction of cable stayed bridge systems. The arrangement of stays, girders and pylons is subject to highway requirements, site conditions and aesthetic performances.