Ain shams University

Faculty of Engineering

Dynamic Response of Cable Stayed Bridges

BY

MOHAMED NOOR ELDEEN SAAD EL-SAYED FAYED

A THESIS

SUBMITTED IN FULFILLMENT FOR THE REQUIREMENTS

OF DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING (STRUCTURAL)

SUPERVISED BY

Prof. S.A. SAAFAN

Prof. H.A. BUCHHOLDT

Prof. G. NASSAR

Assoc. Prof. H.A. EREIBA

Cairo - 1988

Examiners Committee

Name, Title and Affiliation	**Signature**
1. Professor HUGH TOTTENHAM Civil Engineering Department Southampton University, U.K.	
2. Professor ADEL HELMY SALEM Structural Engineering Department Ain Shams University, Cairo, Egypt.	
3. Professor H.A. BUCHHOLDT Civil Engineering Department Polytechnic of Central London, U.K.	
4. Professor SAAFAN A. SAAFAN Structural Engineering Department Ain Shams University, Cairo, Egypt	S.A. Saafan

Date: /4 / 8 /1988

بسم الله الرحمن الرحيم

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.

Date : 1 / 8 / 1988

Signature : Noor Fayed

Name : Mohamed Noor El Deen Saad El Sayed Fayed

0

SUPERVISION COMMITTEE

1. Professor SAAFAN A. SAAFAN
   Structural Engineering Department
   Ain Shams University, Egypt.

2. Professor H. A. BUCHHOLDT
   Civil Engineering Department
   Polytechnic of Central London, U.K.

3. Professor GAMAL EL-DIN NASSAR
   Structural Engineering Department
   Ain Shams University, Egypt.

4. Associate Professor HASSAN A. EREIBA
   Structural Engineering Department
   Cairo University, Egypt.

ACKNOWLEDGMENTS

It is a great honour for me to complete my work with sincere thanks to Professor S.A. Saafan, Ain Shams University, and Professor H.A. Buchholdt, Polytechnic of Central London. They had so kindly and so carefully assisted and collaborated with me in every step of this work. My acknowledgement represents inadequate expression of appreciation for their guidance, encouragement, valuable ideas and excellent supervision.

With my great pleasure, I wish to express my gratitude to Professor G. Nassar, Ain Shams University. Particular thanks are due to Associate Professor H.A. Ereiba, Cairo University, for his perfect supervision, continued encouragement and useful instruction which were of great help to me.

My sincere appreciation and grateful thanks to Professor Regan, Head of Department of Civil Engineering at the Polytechnic of Central London, for his concern and interest throughout the course of this work. In addition, I express my thanks to the staff of the computing services and the technical staff at the Polytechnical of Central London especially the technical supervisor Mr. J. Davis. Thanks are also due to M. Alphonse for typing this thesis.

Finally, I would like to convey my thanks to Dr. Moossavinejad, Dr. Iannuzzi, Dr. Karbassi and Dr. Daneshjoo, at the Polytechnic of Central London, for their help and active interest in my work which has been of great benefit.

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.

CONTENTS

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, Immanual 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 crowed 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.