RELIABILITY ANALYSIS OF SUSPENSION BRIDGES FOR WIND FORCES

by

SAEID POURZEYNALI MIANKOUH

Department of Civil Engineering

Submitted
in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

to the

Indian Institute Of Technology Delhi
Hauz Khas, New Delhi- 110 016, India

August, 2001

CERTIFICATE

This is to certify that the thesis entitled, " **Reliability Analysis of Suspension Bridges for Wind Forces**", being submitted by **Mr. Saeid Pourzeynali Miankouh,** to the Indian Institute of Technology, Delhi, for the award of the degree of **DOCTOR OF PHILOSOPHY** in Civil Engineering, is a record of the bonafide research work carried out by him under my supervision and guidance. He has fulfilled the requirements for the submission of this thesis, which to the best of my knowledge, has reached the requisite standard.

The material contained in this thesis has not been submitted, in part or full to any other University or Institute for the award of any Degree or Diploma.

Prof. T. K. Datta
Civil Engineering Department,
Indian Institute of Technology,
New Delhi-110 016, India

August, 2001

ACKNOWLEDGEMENTS

I express my deep sense of gratitude to **Prof. T. K. Datta** for his inspiration, valuable guidance and discussions, constant encouragement, and companionship throughout this research work. I am also very thankful to Dr. A. K. Jain and Dr. G. V. Ramana for their valuable suggestions and help during this period.

I want to tender my grateful thanks to the **ministry of Science, Research and Technology** and **University of Guilan** under the Islamic Republic of Iran for their scholarship and financial support throughout this research work.

I also want to express my deep thanks to my parents that without their help, blessings and encouragement throughout my life, I couldn't reach to my targets. I would always be grateful to my wife and children for their patience, understanding, love, help and encouragement during the research on this thesis. I also would like to express my sincere thanks to my relatives that without their help I was not able to continue this research work.

My sincere thanks to all my research friends in India for their help and friendship during my stay in India.

August, 2001 (Saeid Pourzeynali)

ABSTRACT

Reliability analysis of suspension bridges against different types of failure due to wind induced vibrations is investigated. For this purpose, a finite element method (FEM) is presented for finding the critical flutter wind speed and for obtaining the buffeting response of suspension bridges. For determining the buffeting response, a spectral analysis in frequency domain is used. In order to verify the developed FEM procedure, the results are compared with those obtained by the continuum approach. For the numerical study, the Vincent Thomas and Golden Gate Suspension Bridges are taken as illustrative examples. It is found that there is practically no difference between the results obtained by the two approaches. Before the reliability analyses are performed, an extensive parametric study is carried out to understand the behavior of suspension bridges under wind induced vibration. The results of the study indicate that the buffeting response of suspension bridges is very sensitive to the variation of some important parameters such as flutter derivatives, mean wind speed, static wind force coefficients, etc. in the vicinity of the critical flutter speed. However, they do not have much influence on the response at wind speeds away from the critical flutter wind speed.

In the reliability analysis, uncertainties due to randomness of annual maximum mean wind speed at the bridge site over the design life of the structure, random characteristics of the gustiness of the wind velocities, and the probabilistic nature of the structural properties of the bridge are taken into account. Reliability of the same two suspension bridges against first passage failure due to gustiness of wind velocity, reliability against flutter failure due to annual maximum mean wind speed during design life of the bridge, reliability against buffeting response (bending stress in the bridge deck at the critical nodes) due to gustiness of wind components, and reliability against cumulative fatigue damage caused by wind fluctuations over the design life of the bridge are carried out.

In the reliability analysis against first passage failure, the probability of exceeding a specified threshold level of stress produced due to the gustiness of wind velocity at the critical nodes along the bridge span is determined using the crossing analysis method. For this purpose, the random crossing of the threshold level is assumed to follow a Poisson model. The conditional probability of failure is weighted by the probability density function of the storm mean wind speed, which is assumed to be a type II distribution given by Thom (1968). It is found that the reliability against first passage failure decreases with the increase in spatial correlation between the wind velocities; also, the stress barrier level has significant influence on the reliability estimate.

Reliabilities against flutter and buffeting failures are evaluated using PRA (probability risk analysis) procedure in which the uncertainties arising from the randomness of material properties, mathematical modeling, flutter derivatives, damping coefficient, ductility of the system, etc. are incorporated through some multiplying factors into the limit state function. All factors are assumed to be independent log-normally distributed random variables. The annual maximum mean wind speed/ storm mean wind speed at the bridge site is assumed to follow Gumbel type I/ extremal type II distribution. The numerical results of the study show that the flutter wind speed may be assumed to be log-normally distributed without introducing much error in the flutter reliability. Further, it is found that the structural damping, number of the storms in a year, and ductility of the system significantly influence the reliability against buffeting failure of the suspension bridges.

The probability of fatigue failure due to wind velocity fluctuation is evaluated using both first order second moment (FOSM) method and full distribution method. For the latter, fatigue life is assumed to follow a Weibull distribution. The reliability against fatigue damage is determined by considering bending failure at the critical nodes along the bridge span. In order to calculate the cumulative fatigue damage, the Palmgren-Miner's rule and S-N curve

approach are used. The annual fatigue damage is calculated by assuming different forms of distribution for the stress range such as, Rayleigh distribution, Beta distribution, Normal distribution, log-normal distribution, Rice distribution, etc. The storm mean wind speed is assumed to follow the extremal type II distribution. A comprehensive parametric study is carried out to show the effect of some important parameters on the reliability against fatigue damage. It is found that the distribution of stress range significantly affects the probability of fatigue failure. The Rayleigh distribution provides the minimum value of reliability, whereas the Normal distribution predicts the maximum value of the reliability. Furthermore, FOSM method predicts the probability of fatigue failure more than that predicted by the full distribution method.

CONTENTS