

# RELIABILITY ANALYSIS OF CABLE STAYED BRIDGES UNDER EARTHQUAKE FORCES

By

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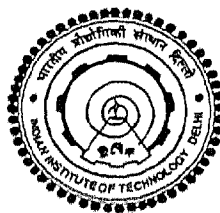
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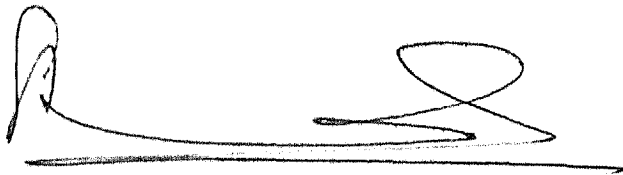
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*PARENTS*

## CERTIFICATE

This is to certify that the thesis entitled, “**Reliability Analysis of Cable Stayed Bridges Under Earthquake Forces**”, being submitted by Mr. *Rehan Ahmad Khan*, to the Indian Institute of Technology, Delhi, for the award of the Degree of ‘**DOCTOR OF PHILOSOPHY**’ in Applied Mechanics, is a record of the bonafide research work carried out by him under our supervision and guidance. He has fulfilled the requirements for submission of this thesis, which to the best of our 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.



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(Rehan Ahmad Khan)

## ABSTRACT

A comprehensive study of reliability of cable stayed bridges for seismic excitation modeled as a stationary random process is presented. The objectives of the study include: (i) to present an analysis procedure to determine the reliability of cable stayed bridges against first passage failure; (ii) to obtain annual damage probability index of cable stayed bridges using the concept of damage probability matrix; (iii) to present a simplified probabilistic risk analysis (PRA) of cable stayed bridge for locations which do not have much recorded earthquake data; (iv) to extend the above PRA of cable stayed bridge for base flexibility including soil – structure interaction; and (v) to conduct an extensive parametric study on two examples of cable stayed bridges in order to highlight the effect of some important parameters on the reliability estimates for seismic excitation.

Reliability analysis of cable stayed bridges against first passage failure is obtained using the method of crossing analysis and poisson's model. The probability of failure is determined by integrating the conditional probability of failure for a specified magnitude of earthquake with its probability density function.

The annual probability of occurrence of different damage states at the critical section of the bridge is obtained using frequency domain spectral analysis with psdf of ground motion defined in terms of earthquake intensity. For each earthquake intensity, the annual probability of occurrence of different damage states are obtained by finding the probability of peak stress exceeding a certain value. In this manner, a damage probability matrix (DPM) is determined for three damage states and four intensities of earthquake. The damage indices are obtained by combining DPM with the annual probability of occurrence of different earthquake intensities.

A simplified PRA procedure for obtaining the reliability of cable stayed bridges is presented for a region, which is surrounded by three earthquake sources having scanty earthquake data. The method of analysis uses risk consistent free field response spectrum and the hazard curves as inputs. They are obtained by assuming the occurrence of earthquake to be a poisson's process and by using an empirical relationship between the magnitude of earthquake and the spectral ordinate for a given time period, and a number of attenuation laws. The mean peak response of the bridge is obtained by the response spectrum method of analysis developed for multi-point excitation like cable stayed bridges. The uncertainties included for the reliability analysis are considered those arising due to seismic input, material properties, modeling, analysis procedure, ductility effect and damage concentration effect. The probability of mean peak response being greater than the capacity of the section is obtained by First Order Second Moment (FOSM) theory of reliability method. The fragility curves are drawn to denote probabilities of failure for different values of peak ground acceleration. Since base flexibility is important for soft soil condition, the PRA of the bridge is obtained by also considering soil – structure interaction. For this purpose, an equivalent modal energy method is used in which soil is replaced by spring – dashpot system.

Two cable stayed bridges are considered as illustrative examples. The first one is harp type system and the second one is fan type system. The effects of important parameters on different types of probability of failure are studied for the two bridges. The parameters include: nature of ground motion, spatial correlation of ground motion, angle of incidence of earthquake, ductility, different uncertainty factors, ratio between the components of ground motion, duration of earthquake, soil condition and base flexibility.

Some of the important results of the study show that (i) uncorrelated ground motion provides lower estimates of the reliability and higher damage indices as compared to the fully correlated ground motion; the difference between the two is significantly more for the soft soil; (ii) the ratio between the components of ground motion and the angle of incidence of earthquake have considerable influence on the reliability estimate; and major and moderate damage indices; (iii) the probability of failure increases with the relative increase in the vertical component of ground motion for both soft and firm soil conditions; (iv) the standard deviation of uncertainty factors has a moderate influence on the probability of failure when they are varied one at a time; when all the variables are simultaneously increased or decreased, there is a considerable change in the probability of failure; (v) the base flexibility due to soil – structure interaction provides higher probability of failure; (vi) a free field response spectrum corresponding to the white noise at the bedrock as input provides higher probabilities of failure as compared to risk consistent response spectrum; (vii) the effect of different parameters on the probabilities of failure is similar for both fan and harp type bridges.

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