VULNERABILITY STUDY OF BUILDING STRUCTURES FOR SEISMIC FORCES

by

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CERTIFICATE

This is to certify that the thesis entitled, **"Vulnerability Study of Building Structures for Seismic Forces"** being submitted by **Ms.Tabassum Naqvi,** 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 her under our supervision and guidance. She has fulfilled the requirements for submission of this thesis, which to the best of my knowledge, has reached the requisite standards.

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

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Dedicated

To

All Special Children

Of

This World

And

My Son

Ayan

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ABSTRACT

Vulnerability analysis of structures using a simplified probabilistic risk analysis (PRA) procedure is presented for regions for which very little recorded earthquake data is available. For the analysis, risk consistent seismic inputs namely, the hazard curve, the risk consistent response spectrum and the PGA levels are used. The study consists of two parts. In the first part of the study, a methodology is presented for obtaining the hazard curve and risk consistent acceleration response spectrums in regions where little or no earthquake data is available. In the second part of the study, a simplified PRA procedure for obtaining the probability of failure of the structures and annual frequency of failure is presented.

For the first part of the study, the hazard curves for a site is obtained by assuming the arrival of earthquake to be a Poisson process. The probability of exceedances of a PGA level for constructing the hazard curve is obtained by weighting the conditional probability of exceedance of PGA level for a given magnitude of earthquake with the probability density function of the magnitude of earthquake. The effects of different earthquake sources influencing the site are duly combined to obtain the final probability of exceedance of a PGA level. The conditional probability is obtained by performing a variance analysis of a number of existing attenuation laws. It is assumed that the PGA value at the site is a random variable for a given magnitude of earthquake M which can assume any one of the 24 values predicted by the 24 attenuation laws. The hazard curve thus obtained is valid for the bedrock level since all the attenuation laws are

generally given for bedrock or hard soil condition. In order to obtain the hazard curve for the free field, PGA amplification due to the overlying soil is duly considered, and the hazard curve is accordingly modified to take into consideration the effect of the overlying soil. Using this hazard curve, a probabilistic microzonation of a region is presented which is surrounded by a number of earthquake sources. Also, a simplified microzonation technique is presented which provides a probability of exceedance of different PGA levels in each microzone. Although the information derived from microzonation study is very useful but it is not directly used as seismic input for a probabilistic analysis procedure (PRA Analysis). The information include effects like effect of soil amplification on the hazard curve, effect of soil nonlinearity in modifying the peak ground acceleration, frequency contents of the ground acceleration and Fourier amplification.

Risk consistent normalized spectrum at the bedrock level is obtained by assuming certain existing empirical relationship, which expresses the ordinates of the normalized acceleration response spectrum in terms of magnitude and epicentral distance of earthquake. Mean and standard deviation of spectral ordinates are then made risk consistent by weighing them with the conditional probability of occurrence of different levels of PGA given certain magnitude of earthquake ordinates. The risk consistent response spectrum thus obtained is valid for bedrock level. Modification of the risk consistent response spectrum for the soil effect is carried out by a random vibration analysis for linear uniform soil and by a simulation procedure for nonlinear uniform or multi-layered soil. A parametric study is carried out to show the effect of soil condition on the risk consistent response spectrum, frequency contents of free field ground motion and its power spectral density function.

In the second part of the study, a simplified PRA procedure is outlined. The method considers risk consistent response spectrum (developed for a site having very less recorded earthquake data) as seismic input and obtains a set of equivalent lateral load on the structure for the seismic effect. Apart from the risk consistent spectrum, free field acceleration response spectrum for white noise input at the bedrock is also used as an earthquake input. Using the lateral load and a superimposed gravity load, a plastic analysis is performed to identify the probable mechanisms of failure for the structure. For an assumed mechanism of failure, the probability of failure of the structure is determined by the first order second moment (FOSM) method. For this purpose, a simplified technique is evolved in which the location of the last hinge formed in the structure is assumed. For that section, the response (bending moment produced due to the lateral load and the vertical load) is computed. The response at the section is then multiplied by four factors, which take into consideration uncertainties of earthquake loading, modelling of the structure and uncertainty simplifications in the analysis and material behaviour. The four factors are assumed to be lognormally distributed random variables having median value to be unity. The lognormal standard deviations of these random variables are either computed or suitably chosen from the existing literature. The capacity of the section is similarly multiplied by two random variables in order to take into account ductility and damage concentration effects. Both random variables are again assumed to be lognormally distributed with certain specified median value and logarithmic standard deviation. Both capacity and response of the section are finally assumed to be lognormally distributed random variable with specified mean values and standard deviations With these values, the probability of failure at the cross section is determined using the FOSM. The proposed method is illustrated by finding the fragility curves and annual frequency of failure (obtained by combining the fragility curve and the hazard curve) for three structures namely, 12 storey steel frame, 9 storey concrete frame and 3 storey masonary wall. An extensive parametric study is conducted to investigate the effect of many important parameters on the fragility curves and the annual frequency of failure of these structures. The parameters include the effect of soil conditions i.e. stiffness of the soil (denoted by shear wave velocity), soil nonlinearity, the nature and the frequency contents of seismic input, the uncertainty factors etc.

The simplified PRA procedure is then extended to obtain the probability of failure for flexible base structures. Base flexibility is assumed to be caused by soil structure interaction. A spring dashpot system is used to represent the base flexibility due soil structure interaction. Modal spectral analysis is used to obtain the equivalent lateral load by obtaining an equivalent modal damping using energy approach. With the set of equivalent lateral load and the set of superimposed vertical load, similar analysis as described above is performed to obtain the probability of failure of the flexible base structures. The analysis is presented for two types of seismic inputs namely, risk consistent response spectrum and the white noise input at the bedrock level which can duly take into account damping of the system for obtaining the lateral load. The method is

applied to obtain the fragility curve for the same 12 storey steel frame with flexible bases. An extensive parametric study is conducted to investigate the effect of different important parameters on the fragility curve and the annual frequency of failure. The parameters include soil condition such as stiff and soft soil, nonlinearity of the soil, input spectrum and the degree of base flexibility.

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