RESPONSE OF 3-D TALL BUILDINGS TO EARTHQUAKE EXCITATION

THESIS
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by
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Dedicated to my wife and children

CERTIFICATE

This is to certify that the thesis entitled, "RESPONSE OF 3-D TALL BUILDINGS TO EARTHQUAKE EXCITATION", being submitted by Shri A. K. ASTHANA, 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.

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A. K. ASTHANA

ABSTRACT

Some studies on the elastic earthquake response of three-dimensional (3-D) tall buildings are presented. The building is modelled as a discrete, lumped-mass multi-degree-of-freedom (MDOF) system. The 3-D model considers 3 dynamic DOF at each floor level - horizontal translations in two orthogonal directions and a rotation about a vertical axis. When foundation interaction is considered, 5 base DOF are included in the analysis.

The max. responses of the fixed base buildings subjected to horizontal ground-motion due to earthquake excitation are obtained by 3 different methods : (i) Conventional modal analysis using the earthquake acceleration response-spectrum (ii) Spectral (or random vibration) analysis using the powerspectral-density-function (PSDF) of earthquake acceleration, treating it as a stochastic process and (iii) Random vibration analysis using response-spectrum. In the first method, the conventional modal analysis applicable to planar models of buildings is extended for 3-D buildings. Combination of modal maxima of responses is achieved by the popularly used square-root-of-sum-of-squares (SRSS) method and the recently developed complete quadratic combination (CQC) method. The CQC method accounts for the cross-correlation between modal responses which can be significant for modes with closely spaced natural frequencies. For the second method, the PSDF of earthquake acceleration is derived from its response-spectrum by the approximate method proposed by Kaul. The PSDF of response is obtained by the transfer-function approach which makes use of the complex frequency response function. The third method obtains the mean peak responses of the tall building to random earthquake excitation using the mean acceleration response spectrum as input. The earthquake is assumed to

be a wide-band, stationary, Gaussian process over the frequency range of interest. Using the principles of random vibration, the mean peak responses are obtained as functions of maximum responses in each mode of vibration. The results of the example problems on both symmetric and asymmetric buildings obtained by the three methods are compared to show that the third method provides a good estimate of the response quantities at a less computational effort for 3-D tall buildings.

Next the effects of rotational component of ground-motion on the response of 3-D tall buildings are studied by incorporating the torsional response-spectrum in the analysis. The above methods are extended to include the torsional component of ground-motion. The results of the study indicate that the torsion due to rotational component of ground-motion may be more significant than that produced due to translational component of ground-motion.

The effect of soil-structure interaction on the earthquake response of 3-D tall buildings is then investigated by assuming its base to be a rigid, circular disc footing, attached to the surface of a linearly elastic half-space. Five base DOF are considered - horizontal translations in two orthogonal directions, rocking about these two axes and twisting about the vertical axis. Both frequency dependent and frequency independent impedance functions representing the foundation stiffness and damping are considered in the analysis. The complex frequency responses due to unit harmonic ground acceleration (expressed in complex domain) are obtained by extending the method of Chopra and Gutierrez, which was proposed for planar buildings. The PSDF of response is obtained from the PSDF of earthquake acceleration by the transfer function approach. Some parametric studies are carried

out on the example buildings to study the effect of soil parameters on the response of 3-D tall buildings. In general, it is observed that the effect of soil-structure interaction on the response becomes quite significant at lower frequencies.

Finally an approximate method for obtaining the mean peak response of 3-D tall buildings including foundation interaction is developed. Using an equivalent modal damping corresponding to each mode of vibration of the flexible base structure, the method computes the mean peak responses of the building from a given earthquake response spectrum. The equivalent modal damping for each mode of vibration is derived by an approximate energy approach proposed by Novak. The use of the equivalent modal damping enables the simplicity of modal analysis to be retained in the computational scheme and allows the method of random vibration analysis (as presented in Chapter-3) to be extended for the case of foundation interaction. The responses obtained by the proposed methods are compared with those of the spectral analysis (Chapter-5) for a number of cases.

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