THE COMMONALITY OF DYNAMIC ANALYSIS PROCEDURES FOR EARTHQUAKE AND WIND LOADINGS

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SUMMARY

The results of a recent study on the development of parallel dynamic analysis procedures for handling earthquake and wind loadings on structures are presented in this paper. These procedures are based on the use of response spectra and a participation factor approach for handling the wind loading which is similar to that used for earthquake base excitation.

INTRODUCTION

The purpose of this paper is to present the commonality of dynamic analysis procedures employed for evaluating the effects of wind and earthquake excitiaton. In addition a procedure is described for constructing response spectra for wind loading, which in turn permits the use of modal analysis techniques in a manner similar to that employed for earthquake engineering; the procedures are based in part on random vibration techniques.

SOLUTION OF THE EQUATION OF MOTION

The equations of motion and their solution are outlined in Table 1. For convenience in handling wind excitation, the loading is divided into two components: a static component and a dynamic component. The steps in Table 1 are identified as "total" if both components are included and "dynamic" if only the dynamic component is included. The solution follows a form similar to that recommended by the Applied Technology Council (Ref. 1). For the computation of modal base shear, A is the spectral acceleration for earthquake loading. P_{eff} is the effective spectral wind pressure of the dynamic component of the wind loading. As employed herein the wind spectrum is computed for the average wind velocity in fps at the top of the building.

For wind, drag coefficients are taken as one for the computation of the response spectrum. Recommended values of drag coefficients and vertical distribution of the wind pressure are included in the computation of the participation factors, as presented in Fig. 2.

STEPS TO DRAW FLUCTUATING WIND RESPONSE SPECTRA

The steps necessary for drawing wind response spectra are based on a study presented in Ref. 2 and can be summarized (See Fig. 3) as follows:

1) Draw the mean wind velocity ($\bar{V}$) and wind pressure ($P_o = 1/2\ \rho V^2$). These lines represent the unamplified response of a single degree of freedom system subjected to a mean wind flow.

2) Obtain the base lines for the fluctuating component by multiplying

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the mean wind pressure by the effective pressure coefficient (P_r) presented in Table 2, and the mean wind velocity by $\sqrt{P_r}$. These reduced base lines represent the wind pressure and the effective wind velocity that will be felt by a rigid body associated with the fluctuating component of the turbulent wind flow.

3) Amplify the fluctuating base line to account for the dynamic effects of the wind. In the velocity region of the spectrum a single amplification factor is used, whereas in the pressure region more than one control point is employed. The recommended control points and the amplification factors are presented in Table 3.

COMPARISON OF EARTHQUAKE AND WIND DESIGN LOADINGS

Earthquake and wind design loadings are dependent on the geographic location and the structural properties of the building. One possible procedure for the comparison of earthquake and wind design loads is the evaluation of the base shear coefficient. For wind, the base shear coefficient can be computed by multiplying the distributed pressure times the exposed area and then dividing by the weight of the structure:

$$V_w = \frac{P \times Area}{W}$$

As an example the seismic and wind provisions of the latest edition of the Uniform Building Code were studied for a typical geographic location. In this case, the base shear coefficients were computed for a set of buildings having the same cross section but varying heights. The results and the cross sections studied are presented in Fig. 4. It can be seen that for lower buildings earthquake loading is the dominant parameter for design, whereas for taller buildings, winds become more important.

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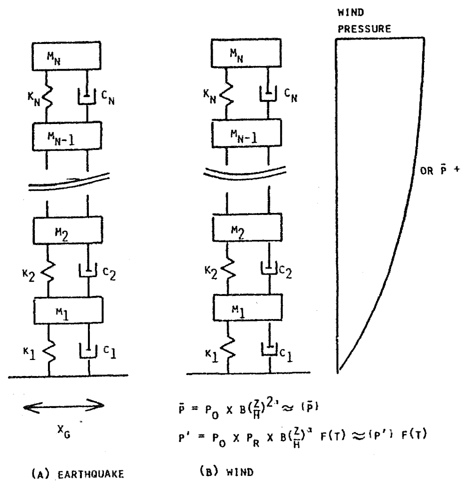

FIG. 1 TYPICAL IDEALIZED BUILDING

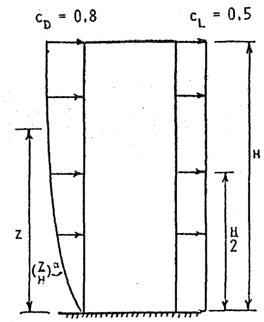

FIG. 2. DRAG COEFFICIENTS AND VERTICAL PRESSURE DISTRIBUTIONS FOR THE COMPUTATION OF PARTICIPATION FACTORS

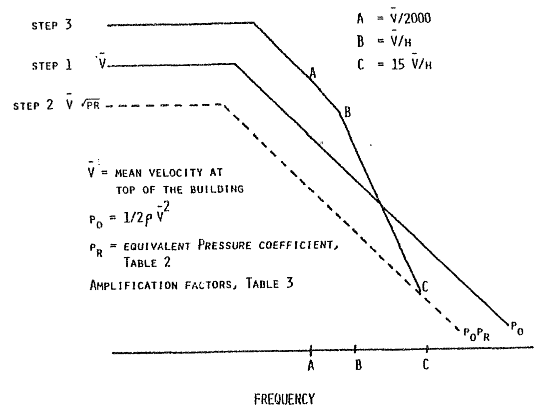

FIG. 3 SCHEMATIC REPRESENTATION OF WIND RESPONSE SPECTRUM

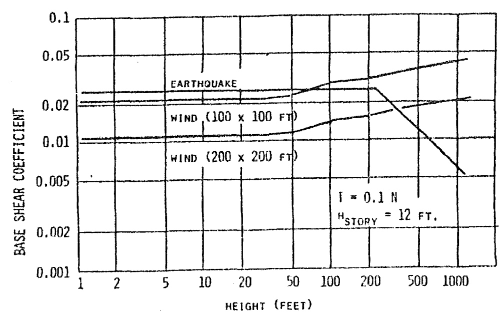

FIG. 4. COMPARISON OF U.B.C. WIND AND EARTHQUAKE TYPICAL BASE SHEAR COEFFICIENTS

TABLE 1. EQUATIONS OF MOTION AND THEIR SOLUTION

	EARTHQUAKE	WIND
EQUATION OF MOTION	$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = [M]\{\ddot{X}_G\}$	$[M]\{\ddot{X}\} + [C]\{\dot{X}\} + [K]\{X\} = \{\bar{P}\} + \{P'\}$
SOLUTION (TOTAL)	$\{U\} = \sum_{I=1}^{N} \phi_I C_I D_I$	$\{X\} = \sum_{I=1}^{N} \phi_I C_I D_I + [K]^{-1}\{\bar{P}\}$
PARTICIPATION FACTOR (ONLY DYNAMIC)	$C_I = \frac{\{\phi_I\}^T [M] \{1\}}{\{\phi_I\}^T [M] \{\phi_I\}}$	$C_I = \frac{\{\phi_I\}^T \{P'\}}{\{\phi_I\}^T [M] \{\phi_I\}}$
MODAL BASE SHEAR (ONLY DYNAMIC)	$V_{OI} = \frac{(\{\phi_I\}^T [M] \{1\})^2}{\{\phi_I\}^T [M] \{\phi_I\}} \cdot A$	* $V_{OI} = \frac{\gamma_I (\{\phi_I\}^T [M] \{1\})^2}{\{\phi_I\}^T [M] \{\phi_I\}} \cdot P_{EFF}$
DISTRIBUTION OF MODAL BASE SHEAR (ONLY DYNAMIC)	$F_I = \frac{[M]\{\phi_I\}}{\phi^T [M] \{1\}} V_{OI}$	
TOTAL STORY SHEAR	$\{F\} = \sum \{F_I\}$ OR $\{F\} = (\sum \{F_I{}^2\})^{1/2}$	$\{F\} = \{\bar{P}\} + \sum \{F_I\}$ OR $\{F\} = \{\bar{P}\} + (\sum \{F_I{}^2\})^{1/2}$

* NOTE: $\gamma_I = \frac{\{\phi_I\}^T \{P'\}}{\{\phi_I\}^T [M] \{1\}}$

TABLE 2. EFFECTIVE PRESSURE COEFFICIENTS

WIND EXPOSURE	α COEFFICIENT	P_R 1σ	P_R 3.5σ
CITY	0.35	$2.05\ H^{-0.40}$	$7.17H^{-0.40}$
SUBURBAN AREAS	0.22	$0.76\ H^{-0.27}$	$2.67H^{-0.27}$
OPEN COUNTRY	0.14	$0.27\ H^{-0.14}$	$0.95H^{-0.14}$

TABLE 3. AMPLIFICATION FACTORS

% CRITICAL DAMPING	VELOCITY		PRESSURE	
		$\bar{V}/2000$	$\bar{V}/H$	$15\ \bar{V}/H$
1	3.53	5.36	5.10	1.0
2	2.74	4.21	3.66	1.0
5	2.24	3.25	2.60	1.0
10	1.64	2.43	1.87	1.0