OPTIMUM DESIGN OF A CHIMNEY FOR DYNAMIC INPUTS

by
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SUMMARY

In this paper, an optimum design problem of a chimney for dynamic inputs is investigated. These dynamic excitations can be taken as applied forces, ground motions or equivalent seismic forces. Optimization is considered as to produce minimum weight chimney. The chimney is assumed to behave linearly and to be of the shear-building type. The problem is formulated as a multidegree freedom system. The chimney is divided into as many sections as is needed. An iterative approach which involves a modal analysis in each cycle is presented to obtain the optimum design. The design velocity spectrum is used to accelerate the procedure. It has been found that the method suggested converges rapidly and it can easily be applied by a design engineer.

INTRODUCTION

Recently, a considerable amount of literature has been published in the area of optimum structural design. Hence, various optimization procedures have been developed for static and dynamic analysis of structures. In the area of optimum seismic structural design, there are studies dealing with shear buildings such as (1), (2), (3). The technique given by Rosenblueth and Asfura (3) seems to suit best for chimney type structures. This approach with some modifications is applied to obtain an optimum design of a chimney under seismic loads.

MATHEMATICAL FORMULATION

The chimney with continuous mass distribution is divided into n sections of equal length. The thickness of the cross-section varies linearly along the height of the chimney and it is to be constructed in reinforced concrete. There is also a brick lining inside the chimney. Bending deformations would be predominant, if the chimney is long compared to its cross-sectional dimensions. Bending stresses at each section will be

$$\sigma_i = \frac{N_i}{A_i} + \frac{M_i}{S_i} \qquad (1)$$

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where N_i is the normal force due to the weight of the chimney above that section, M_i bending moment due to lateral load, A_i is the area of the cross-section and S_i is the section modulus of the cross-section.

Starting with any design of the chimney, the fundamental period of vibration of the chimney can be obtained by using the iterative procedure given by Çakıroğlu and Özmen (4). Performing modal analysis yields q_i lateral load, M_i bending moment and modal displacement at each section. If the allowable stresses in concrete and in steel are σ_{ca} and σ_{sa} respectively, then the constraints for the design will be $\sigma_{ci} \leqslant \sigma_{ca}$ and $\sigma_{si} \leqslant \sigma_{sa}$. The objective function for minimization is

$$W = \int_0^H \pi (D_m)_i \; t_i \; \rho_i \, ds \qquad (2)$$

where ρ_i denotes the density, $(D_m)_i$ is the mean diameter and t_i is the thickness of the cross-section. The integral is taken along the height of the chimney.

Using the initial design data denoted by superscripts zero, new $(D_m^{(1)})_i$, $t_i^{(1)}$ and $I_i^{(1)}$ are determined by making the stress restrictions active at each section. Since a linear variation in D_m and t is considered along the height, this calculation can be done only at the base of the chimney. With these new values, the fundamental period of the chimney can be assumed as $T^{(1)} = \alpha^{\frac{1}{2}} T^{(0)}$

in which

$$\alpha = \frac{\int_0^H \alpha_i q_i \phi_i \, ds}{\int_0^H q_i \phi_i \, ds} \quad , \quad \alpha_i = \frac{I_i^{(1)}}{I_i^{(0)}} \qquad (3)$$

Here, ϕ_i's are the modal displacements. Simpson's rule is used to evaluate the integrals. Analysis is repeated with a moment of inertia equal to $\beta I^{(1)}$. β is obtained as illustrated in "Fig.1". Here V is the design velocity spectrum. The convergence of the method is very rapid if the design velocity spectrum increases with the period in the neighborhood of the fundamental period of the structure (3).

EXAMPLE

The following data for a chimney is used: the height of the chimney $H = 75$ m; the allowable stresses for concrete $\sigma_{ca} = 80$ kg/cm^2 and for steel $\sigma_{sa} = 2000$ kg/cm^2; the modulus of elasticity $E = 0.2925 \times 10^6$ kg/cm^2; the density of concrete shell is 2,4 t/m^3 and of the brick lining is 1.8 t/m^3. The design velocity spectrum taken from reference (2) with 2 % damping given in "Fig.2" is used. For modal analysis, Housner's design acceleration spectrum with a maximum acceleration $a_{max} = 0.25$ g is considered (5). In the calculations, the first three modes are taken into account. Seismic provisions in Turkey require that the total lateral load values calculated from the modal analysis shall not be less than 70 % of the lateral load values determined by using a seismic coefficient. Therefore, in considering the ductility factor for the analysis, a value determined by dividing the maximum lateral load obtained from the modal analysis to 70 % of the lateral load calculated from the seismic coefficient method. A value of 0.20 is taken for the seismic coefficient.

The results are presented in Table 1. The initial mean diameter D_m, thickness t and moment of inertia I, stress in concrete σ_c and stress in steel σ_s are given for the initial and final cases. The final values were obtained in two cycles. The stresses in concrete and in steel are within 10 % of the allowable values compared to 30 % in the case of the initial design. The decrease in the total weight of the chimney including the concrete shell and the brick lining is shown in "Fig.3". There is about 40 % change in the total weight in two cycles. The decrease in the weight of the concrete shell alone is given in "Fig.4" and the change in this case is about 63 %. The difference is due to the fact that other than its own weight, the brick lining is not a load carrying part of the structure.

CONCLUSIONS

The presented approach for the optimum design of a chimney under dynamic loads will be a quite useful tool for a design engineer. It converges rapidly when the design velocity spectrum has a positive slope in the vicinity of the fundamental period of the chimney. This is usually the case in considering the damping ratio for a reinforced concrete chimney.

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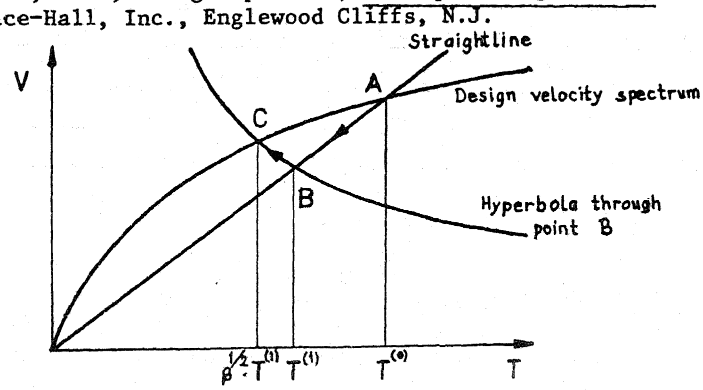

FIG. 1.

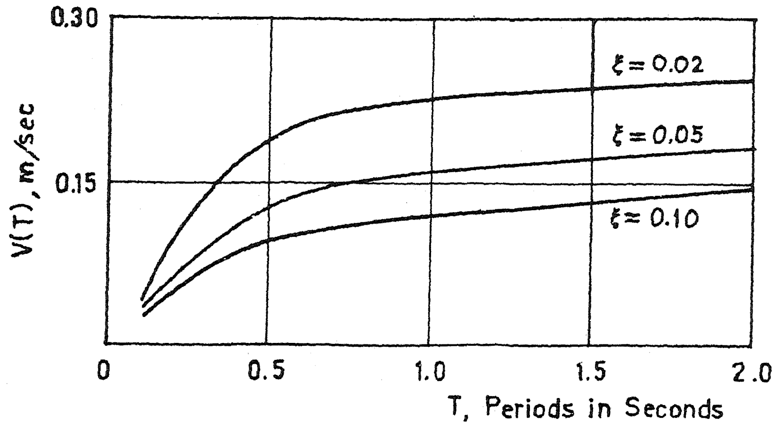

FIG. 2.

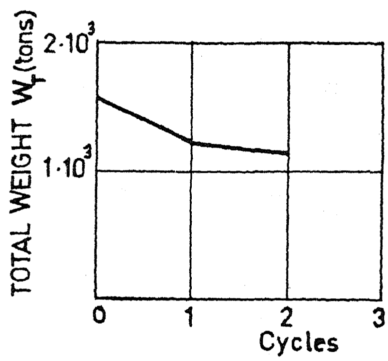

FIG. 3.

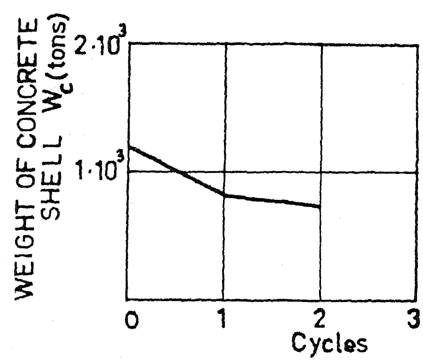

FIG. 4.

		Top			Base				
		D_m (m)	t (m)	I (m^4)	D_m (m)	t (m)	I (m^4)	σ_c (kg/cm^2)	σ_s (kg/cm^2)
Initial	Concrete	4.160	0.200	5.667	6.400	0.60	62.309	55.7	1392
	Brick	3.164	0.114	-	5.223	0.345	-	-	-
Final	Concrete	4.110	0.150	4.095	6.600	0.30	33.940	72.0	1798
	Brick	3.614	0.114	-	5.725	0.345	-	-	-

TABLE 1.