EARTHQUAKE STRUCTURAL DESIGN BASED ON OPTIMALITY CRITERION

by

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SYNOPSIS

This paper presents the results of an optimum design for frame structures subject to earthquake motions. The objective of the design procedure is to obtain a minimum weight for a structure without exceeding the strength limits that are determined by the stiffness requirement and optimality criterion. The numerical examples provided are based on the lateral forces recommended by the U. S. Uniform Building Code and Housner's response spectrum of El Centro, 1940.

INTRODUCTION

Various optimization techniques have been developed for static and dynamic structural design (1). One of these, the powerful technique of optimality criterion, has been extensively used for large structural systems in aerospace engineering (4). Venkayya and Cheng recently extended the optimization algorithm to include structures subjected to ground motions (3). In this report, the optimality criterion is used to analyze an earthquake structural design that is based on the lateral forces recommended by the U. S. Uniform Building Code (UBC) and the response spectrum of El Centro, 1940, proposed by Housner (2). Numerical results are provided to show the effect that the two design principles have on optimum solutions.

GENERAL CONSIDERATIONS

The displacement method employed in this study takes into consideration structural mass, nonstructural mass, damping, and P-Δ effect. Each node of a system has three degrees of freedom that are associated with axial and bending deformations and consistent mass formulations. The matrix equation is solved by modal analysis for which the acceleration spectrum can be used for earthquake response. For the design based on the UBC, the structural and nonstructural masses are also included; Z and K are assumed to be one. The period T is determined by using either the eignenvalue analysis or the equation in the Code. The recursion technique for achieving the optimality criterion is used in this work.

NUMERICAL EXAMPLES

The five-story-one-bay elastic frame shown in Fig. 1 has been studied from the viewpoint of the following loading conditions: A) Housner's average acceleration spectrum of El Centro, 1940, which has a factor of 2.7 and 5% damping, and B) lateral forces recommended by UBC. For Case A, other considerations include: 1) No P-Δ effect, 2) P-Δ effect resulting from structural and nonstructural weight, and 3) P-Δ effect resulting from structural and nonstructural weight in addition to axial forces (not mass) of 45.36 kips applied to each column. For Case B, the natural period, T, is obtained by 1) evaluating the eigenvalues of the structure on the basis of

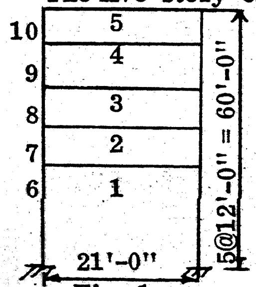

Fig. 1

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the structural member sizes obtained through the optimum design process and 2) using the equation T=0.10N in the Code. The modulus of elasticity is 29 x 10^3 ksi, the structural material has unit weight of 0.283 lbs/cu in., and the nonstructural mass is 180 lbs/in. for each floor. The allowable stress is 29 ksi, which is compared with the combined stresses of the axial force and bending of all members. The allowable shear stress is 19 ksi. The design results based on the first mode are shown in Table 1 in which the member numbers are given in Fig. 1. The maximum deflections corresponding to the five cases are 4.74, 4.71, 4.61, 8.20, and 7.43 (in.) respectively.

Table 1 - Comparisons of Design Results.

Case	Period (sec)	Weight (lbs)	Member No. (Area in.^{2})*, (Moment Inertia in.^{4})$^+$									
			1	2	3	4	5	6	7	8	9	10
A-1	1.186	9122	15.37* 905.5+	17.00 1117.0	15.15 870.4	11.88 506.1	6.67 131.3	14.75 825.1	12.32 550.4	11.04 428.9	9.30 288.5	6.69 132.0
A-2	1.184	9276	15.63 936.9	17.30 1159.0	15.41 901.4	12.07 523.7	6.77 135.8	14.99 854.3	12.55 573.4	11.24 445.6	9.46 299.3	6.79 136.9
A-3	1.164	9606	16.09 1005.	17.33 1184.0	15.52 927.6	12.22 542.5	7.46 172.56	15.68 948.8	13.23 648.1	11.80 500.7	9.91 335.25	7.20 158.3
B-1	3.924	2806	4.83 81.8	5.26 91.2	4.50 71.4	3.53 42.0	2.45 17.7	4.23 63.6	3.63 44.7	3.31 36.1	2.83 24.9	2.45 17.7
B-2	0.5	4326	7.85 206.2	8.79 236.6	7.15 176.0	5.42 95.3	3.20 26.7	6.79 160.8	5.61 103.3	5.03 80.0	4.21 52.4	3.08 24.3

CONCLUSIONS

1. A great deviation of design results exists for the spectrum method and UBC.

2. UBC requires a lighter structural design.

3. Different methods of obtaining the natural period recommended by UBC can significantly yield different design results.

4. The P-Δ effect demands a heavy structural design.

5. The optimum design of a given structure is in the neighborhood of a certain period of the response spectrum in spite of various changes of the P-Δ effect and superimposed masses.

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