OPTIMUM DESIGN WITH EQUIVALENT SEISMIC LOADS

by

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SYNOPSIS

Methods for structural optimization of aseismic buildings. Design loads are assumed to be specified by codes as a function of structural dynamic response. Applications of an optimality criterion to steel braced buildings and of mathematical programming to gravity dams are presented. Results show feasibility of the methods for practical design.

MOTIVATIONS

Despite the growing researches and applications of structural optimization during the last 10 years, little litterature exists in connexion with aseismic design. Authors deal with frames(1),or shear-type buildings(2).Optimization is also proposed for rationalizing code formats(3).

Practical design applications call for simple algorythms but able to handle realistic(complex)structural schemes. This paper reports experiences and results in this direction.

OPTIMALITY CRITERION

The most used method of structural optimization for framed structures is"fully stressed design". The traditional iterative procedure has the following operations at each step: a)analyze a given structure and find the maximum stress in each member(or groups of members constrained to have the same size), b) update the member sizes in proportion to the ratio actual/limit design stresses, then go to a).

In the aseismic design of framed buildings step a) implies the following operations: a1) reduce the total stiffness matrix to lateral st. m., a2) eigenvalues(and eigenvectors)analysis and determination of seismic design loads from an average(code)acceleration spectrum, a3) find stresses for a given combination of vertical and horizontal design loads.

In the aseismic design of(braced)framed buildings

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step b) implies: b1) update beam and column sizes according to the above stress ratio, b2) update limit design stress for bracing (diagonals and columns) according to actual/max top displacements, b3) update sizes of bracings.

With respect to a traditional "fully stressed design" steps a2) and b2) are the only different items. Details of this procedure and test results are reported in (4). As an example, in fig.1 is shown the convergence of the procedure for the 12-story steel buildings of fig.2. Seismic loads are assumed to be triangularly distributed over the elevation in both principal horizontal directions, with a total shear seismic coefficient

$$c = \frac{0.05}{\sqrt[3]{T_o}}$$

and a top displacement limited to 1/500 of the total height. Zigzaging in the convergence is mainly due to discrete (standard HE profiles, constant stiffness every 3 storys) variables, as the comparison with a static (wind) fully stressed procedure shows. In both cases 6 analyses lead to weight-stationary feasible solutions, with a computer time of 3 min. on Univac II06.

MATHEMATICAL PROGRAMMING

The above results seem to restrict the use of m. p. to cases where the design variables cannot be easily related to member sizes. In the latter cases results have been obtained for gravity dams optimum profiles (5). Features of the problem are: a) analyses are the more time-consuming part of the procedure, b) static condensation of the stiffness matrix is as nearly time consuming as a new eigen-analysis, c) system dynamic strongly depends on ground and water interaction, d) significant design variables may be but a few (see fig.3).

Consequently, the following procedure has been assumed: a) stresses in the nodal points have been expanded in polynomia: linear at the starting point, quadratic near the optimum. This couples well with the SUMT n.l.p. method, who requires increasing precision in the definition of the boundary of the feasible region as the procedure goes on.
b) complete eigen-values,-vectors, analyses are done only at the starting point and near the optimum. Intermediate behaviour is determined with approximate eigen-values evaluations, on the basis of the Rayleigh's quotient:

$$\omega^2 = \frac{\{U\}^T [K^*] \{U\}}{\{U\}^T [M^*] \{U\}}$$

where $\{U\}$ is the last-determined eigenvector and $[K^*]$, $[M^*]$ are the variated stiffness and mass matrices.
c) ground is included in the finite element model. Water effect is taken into account with an amplification coefficient for lateral pressure, depending on the first period of the system .

For the example in fig.3, with 4 design variables, I2 static and 2 dynamic analyses were needed for the optimization, i.e. 15 min. computer time.

CONCLUSIONS

Traditional methods of structural optimizations may be applied, with minor implementations, to aseismi design. For practical purposes,optimality criteria (fully stressed d. with limitations on displacements) seem to be suggested for framed buildings,while mathematical non linear programming for "shape optimization" problems. The efficiency of the methods depends on a proper selection of approximated evaluations in the procedures. If this is done, the calculations for the required dynamic analyses result only in a small fraction of the total work for optimization.

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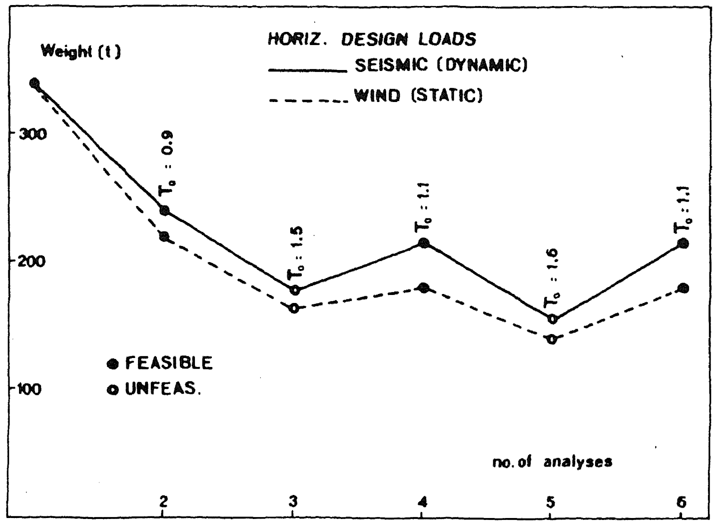

FIG.1

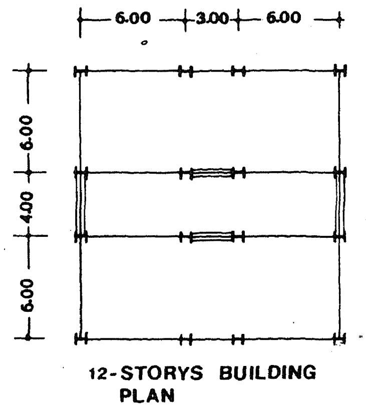

FIG.2

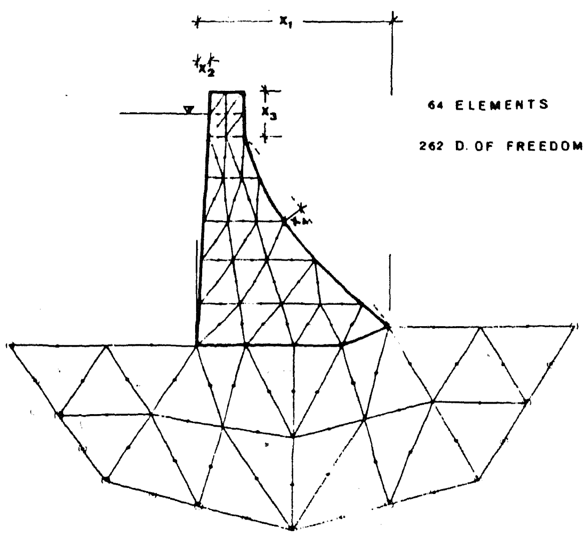

FIG.3

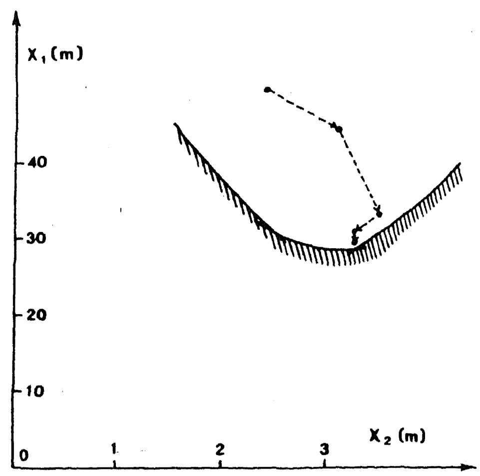

FIG.4