

**ANIL K. CHOPRA****Current Research Projects****Dynamic Analysis Procedures for Performance-Based Seismic Engineering of Buildings**

Current structural engineering practice is to estimate seismic demands on buildings are determined by nonlinear static analysis of the structure subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Both the force distribution and target displacement are based on the assumption that the response is controlled by the fundamental mode and that the mode shape remains unchanged after the structure yields. These existing procedures are not consistent with structural dynamics theory.

The goal of our research is to develop improved procedures based on structural dynamics theory that are simple enough for application to design of new structures and retrofit of existing structures. Empirical equations have been developed for estimating the target displacement due to far-fault or near-fault ground motions. Based on structural dynamics theory, a modal pushover analysis (MPA) procedure has been developed that retains the conceptual simplicity and computational attractiveness of current procedures with invariant force distribution. This new method for estimating seismic demands on buildings at low performance levels, such as life safety and collapse prevention, has been evaluated for a wide range of buildings and ground motion ensembles.

After demonstrating the effectiveness of MPA, it has been extended to unsymmetric-plan buildings, and has also been extended to special steel-moment resisting frames (SMRF) and reinforced concrete SMRFs. Currently, we are evaluating its accuracy in estimating seismic demands for tall concrete shear wall buildings and unsymmetric-plan buildings.

Other applications of MPA have included Incremental Dynamic Analysis, collapse fragility curves, and scaling of ground motions for nonlinear response history analysis of buildings.

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**Earthquake Analysis of Concrete Dams**

Seismic safety evaluation of proposed or existing concrete dams requires analysis of a large three-dimensional finite element (FE) model of the dam including several factors: dam-water interaction, including water compressibility, reservoir bottom interaction, and the large extent of the reservoir in the upstream direction; dam-foundation interaction, including foundation inertial effects, material and radiation damping, and the semi-infinite extent of the foundation rock; and spatial variations in ground motion. Over the past three decades, research has conclusively demonstrated that these factors significantly influence the earthquake response of dams and must be rigorously treated.

Although dam-water-foundation interaction effects are rigorously treated in EAGD-84 and EACD-3D-96, these computer codes, resulting from our previous research, have several

limitations: linear systems, homogeneous foundation rock, uniform canyon, and spatially-uniform ground motion, assumptions that are inappropriate for many practical situations. Recently, we have extended the substructure method for dynamic analysis of arch dams subjected to ground motions that vary around the canyon and implemented in the EACD-3D-2008 computer program. The earthquake response of Mauvoisin Dam (Switzerland) and Pacoima Dam (California) to spatially-varying ground motion recorded during past earthquakes was computed and compared with their recorded motions with the objective of understanding (1) several issues in the modeling of dam-water-foundation rock systems; and (2) significance of spatial variations in ground motions on dam response.

The ultimate objective of this project are to develop efficient and accurate transient nonlinear three dimensional FE analysis of dams, including dam-foundation-fluid interaction effects using realistic models for foundation and fluid domains—subjected to spatially-varying ground motions. Such an analytical capability will be a major improvement beyond the present state of research and practice.

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