

## **DAMS, EMBANKMENTS, AND RESERVOIRS**

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This paper on the performance of dams, reservoirs, levees, and other embankments during earthquakes covers current methods of analysis, improvement of existing structures, design of new structures, and needs for developing new knowledge in these areas. The emphasis is on dams because of the relative availability of technical literature and because the author's experience is primarily related to earth dams. Significant differences in earthquake performance of earth dams and other structures are explained.

### **INTRODUCTION**

The usual design practice for dams prior to 1970 was to consider earthquake effects by incorporating in the stability or stress analysis, a static lateral force intended to represent the inertia force induced by the earthquake (National Research Council, 1984). This force usually was expressed as the product of a lateral force coefficient and the force of gravity. The coefficient generally varied between 0.05 and 0.15g depending on the seismicity of the area in which the dam was located and the judgment of the engineer involved. The method was called a pseudo-static analysis in recognition of the fact that static lateral forces were only intended to represent the effects of the actual dynamic earthquake forces that were known to be different.

The pseudo-static analysis was similar to that used for building design in seismically active areas. Hydrodynamic forces were applied to concrete dams according to the procedure developed by Westergaard in the 1920s. Results of studies by Zangar led to the conclusion that consideration of hydrodynamic forces was not necessary for flatter embankment dam slopes. The pseudo-static analysis combined with engineering judgment produced many excellent dams.

A series of events in the 1960s and early 1970s caused engineers to re-evaluate the adequacy of the pseudo-static approach:

1. Many slope failures occurred in the 1964 Alaska earthquake that would not have been predicted by the analysis.
2. Hsingfengkiang Dam, a concrete buttress dam in China, cracked