EARTH DAM MOTION DUE TO A DEEP NUCLEAR EXPLOSION

by

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SYNOPSIS

The motion of Rifle Gap Dam, a 120-ft high, 1500-ft long, rolled earth-fill dam, was measured during its response to the ground motion effects produced by a deep underground nuclear detonation. A two-dimensional finite element model, representing the 100-ft deep alluvial foundation and the dam, was used to compute the motion of the surface of the alluvium and of various points on the dam; measured rock abutment motion was assumed to excite the base of the finite element model. A comparison of the measured and computed peak accelerations and acceleration response spectra indicated that the finite element method is a useful tool for the analysis of foundation and dam response to the effects of induced ground motions, at least for the motion levels observed at Rifle Gap Dam.

INTRODUCTION

The U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, measured and analyzed the response of Rifle Gap Dam to ground motions, similar to earthquakes, which were generated by the RULISON nuclear detonation. The objective of the measurements and analyses was to determine, by full-scale test, the applicability of current seismic design procedures to the design of Corps of Engineers earth and rock-fill dams that are subjected to earthquake effects.

Project RULISON was a part of the PLOWSHARE program of the U. S. Atomic Energy Commission (AEC). It was one of a series of nuclear detonations on the western slope of the Rocky Mountains aimed at increasing the yield of natural gas from tight, gas-bearing formations. The Austral Oil Company conducted this experiment as a commercial venture with the AEC responsible for safety and detonation of the nuclear device. Ground Zero for Project RULISON was located about 6-1/2 miles south of Rulison, Colorado, on Battlement Mesa. The device had a design yield of 40 kilotons and was detonated on September 10, 1969, at a depth of 8442 ft below the ground surface (242 ft below mean sea level) in a stratum of shale and limestone.

Rifle Gap Dam occupies an alluvial valley at the junction of East Rifle Creek and West Rifle Creek, north of the Colorado River. This dam is located about 6-1/2 miles north of Rifle, Colorado, on Highway No. 325. It was about 18-1/2 miles from Ground Zero. At the dam, the valley is approximately 1000 ft wide, has steeply sloping walls, and is filled with alluvial sediments and talus. Borings into this deposit indicate it

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is composed of discontinuous layers and lenses of clay, silt, and sand, with gravel and boulder-sized material interfingered along the edge of the valley.

The dam was completed in 1966 by the Bureau of Reclamation (Bu Rec) for the purpose of providing irrigation water for the fertile downstream valley. The fill material consists of selected mixtures of clay, silt, sand, gravel, and cobbles borrowed from the reservoir area and compacted by tamping rollers. Limestone riprap was placed on the upstream and downstream slopes.(1) The water level in the reservoir was 41 ft below the crest of the dam at the time the RULISON nuclear detonation occurred.

MEASURED DAM MOTION

Motion-measuring instruments were attached to Rifle Gap Dam with the cooperation and support of the Bu Rec. Two other dams in the area were also instrumented: Vega Dam by Bu Rec and Harvey Gap Dam by the National Oceanic and Atmospheric Administration for the AEC. At Rifle Gap Dam, accelerometers, oriented to measure the vertical and the upstream-downstream movement of the dam, were mounted on existing settlement monuments that extended through the riprap and into the rolled fill embankment so that residual displacements of the measurement points, should they occur, could be accurately evaluated. Accelerometers were located on the crest of the dam, at the downstream toe of the dam, and on a mid-slope monument located between the toe and the crest. In addition, accelerometers were located in the gate chamber, founded in rock at the left abutment, and on the surface of the alluvial valley, 470 ft downstream from the toe of the dam. The acceleration-time histories were recorded on magnetic tape recorders and on oscillographs.

The dam began to move about 6.9 sec after the RULISON device was detonated, so the primary wave propagation velocity was a little more than 14,000 ft per second. The motion persisted for over 20 sec and was generally dominated by the vertical component of motion. A complete record of the motion measurements is available.(2) The motion records were digitized and the acceleration response spectra was computed using a computer program obtained from the California Institute of Technology. Table 1 lists the peak recorded acceleration values and the period of the peak acceleration response.

First order horizontal and vertical surveys were made before and after the RULISON event by the Bu Rec. There was no residual displacement of any of the settlement monuments at Rifle Gap due to this event.

COMPUTED DAM MOTION

A two-dimensional finite element computer program for the analysis of dams and foundations under the influence of earthquake motion effects was obtained from the University of California at Berkeley. This program was used to calculate the peak accelerations and acceleration response spectra for an idealized representation of the foundation and dam at Rifle Gap. The finite element mesh was composed of 280 triangular elements and 173 nodal points representing the 120-ft high dam and about 3000 ft of the 100-ft thick alluvial valley underlying the dam.

The California computer program uses a linear-elastic mode superposition computational method. Each of the vibrating nodes is viscously damped and all of the elements are assumed to have the same damping ratio. Each element is assigned an initial or low-strain modulus, a material type (cohesive or cohesionless), and a unit weight. One value of Poisson's ratio is assigned for the entire mesh. The elastic modulus and the viscous damping ratio, however, are empirical functions of material type and strain. The computations are preformed iteratively, i.e., after an initial calculation of the elemental strains due to the applied seismic loading history, the program is capable of changing the modulus and damping ratio of each element to agree with the strain level it experienced during the initial loading history and using these changed values for the next computation. Convergence of subsequent iterations is rapid.

Initial modulus values and depth of the alluvial foundation were obtained by field investigations at Rifle Gap Dam using seismic refraction and surface vibration techniques. Where field values could not be obtained, empirical relationships for small-strain soil moduli were used. The determination of modulus values for the dam and for the foundation, as well as the finite element analysis method, has been discussed in detail.(3) Using the measured acceleration-time history of the gate chamber as the input to the rigid base of the finite element mesh, the peak accelerations of the dam and foundation, at the same locations as the measured motion, were computed along with the acceleration response spectra for the computed motion. Table 1 lists the peak values of the computed acceleration and gives the period of the computed peak acceleration response.

COMPARISON OF MEASURED AND COMPUTED MOTIONS

Agreement between measured and computed accelerations and spectra was improved by judiciously increasing the measured field modulus values by 50 percent. With this adjustment, a comparison of the peak measured accelerations to the peak computed accelerations, as given in Table 1, indicates that the computed motion brackets the measured motion. At the surface of the alluvium, the computed values were less than the measured values. At the toe and at the crest of the dam, the computed vertical value exceeded the measured value, but the computed upstream-downstream component was less than the measured value. The computed values were greater than the measured values on the slope of the dam.

Proceeding from the base rock (gate chamber) to the crest of the dam, the ratio of the measured peak vertical acceleration to the peak upstream-downstream acceleration generally decreased significantly; vertical acceleration was dominant in the rock, but upstream-downstream acceleration was dominant at the crest of the dam. However, the same ratios of computed acceleration do not decrease significantly; the computed vertical acceleration dominated throughout. This difference in measured and computed motion was attributed to the computational assumption that the base of the finite element mesh moved as a rigid body.

Measured and computed peak acceleration response periods showed good agreement in the upstream-downstream direction, but poorer agreement in the vertical direction, particularly at the mid-slope and crest of the dam. This discrepancy may have been due to shallower alluvium under portions of the dam.

Detailed motion comparisons and comparative spectra plots for various moduli and foundation depths are available.(3) However, based only on Table 1, it may be concluded that the computed peak acceleration and the periods of the peak acceleration response generally are in good agreement with the measured values. Because spectral agreements for acceleration are a very demanding comparison criteria, it may also be concluded that the analysis method applied to Rifle Gap Dam is an appropriate tool for the analysis of dams and foundations subjected to earthquakes.

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TABLE 1 Measured and Computed Peak Accelerations and Peak Response Periods

Place	Direction	Measured Acceleration g	Computed Acceleration g	Measured Period sec	Computed Period sec
C	V	0.062	0.073	0.13	0.30
	U-D	0.094	0.052	0.32	0.27
S	V	0.048	0.060	0.13	0.29
	U-D	0.038	0.058	0.32	0.24
T	V	0.046	0.064	0.13	0.18
	U-D	0.052	0.037	0.13	0.18
A	V	0.088	0.072	0.13	0.19
	U-D	0.051	0.050	0.15	0.18
G-C	V	0.028	Base	0.13	Base
	U-D	0.014	Motion	0.30	Motion

LEGEND: C - Crest
S - Slope
T - Toe

V - Vertical
U-D - Upstream-Downstream
A - Surface of Alluvium
G-C - Gate-Chamber (rock)