STRUCTURAL RESPONSE TO MAN-INDUCED GROUND MOTION

by

John A. Blume[I] and Sigmund A. Freeman[II]

SYNOPSIS

The structural response program for the seismic safety aspects of United States underground nuclear detonations has been producing, as a by-product, information and various procedures potentially useful with natural earthquakes. The paper outlines some of the information and references available from this work.

INTRODUCTION

John A. Blume & Associates Research Division has been under contract to the United States Atomic Energy Commission (USAEC), Nevada Operations Office (NVOO) for several years to provide various services including investigations of the effects of ground motion induced by underground nuclear detonations on structures. This work, which also utilizes services of the Earth Science Laboratory of the National Oceanic and Atmospheric Administration for recording facilities and Environmental Research Corporation on ground motion, has produced much data and many procedures useful in the natural earthquake problem. This has been done as a by-product of the basic objective of safety in the nuclear program. Most underground nuclear detonations are conducted at the Nevada Test Site located approximately 100 miles northwest of Las Vegas, Nevada. However, structural response data has also been obtained from underground nuclear detonations at other locations such as Mississippi, Colorado, central Nevada, and New Mexico. Large underground nuclear detonations have been equated to earthquakes having body wave magnitudes up to 6.4. Modified Mercalli intensities have been as high as IV in Las Vegas, Nevada which has a considerable number of highrise structures. For Plowshare events with closer and more sparse population centers, intensities have been as high as VII. Numerous reports and papers have been prepared thus far for NVOO, many of which are available from the National Technical Information Service. In addition, much has been published in the technical literature. All that can be done in this brief paper is to outline and reference structural response work and findings most applicable to the earthquake problem.

REGARDING NATURAL EARTHQUAKES

One of the services provided has been surveys of exposed buildings and structures, with response predictions prior to each large nuclear explosion. Measurements of the actual response have been made at key locations and analyses made as necessary. There has been an ongoing

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[I] President, John A. Blume & Associates, Engineers, 130 Jessie Street, San Francisco, California 94105

[II] Associate, John A. Blume & Associates, Engineers, 130 Jessie Street, San Francisco, California 94105

refinement of empirical data, theory, and procedures. In the early parts of the program, nuclear response data were not available so predictions had to be made based largely upon knowledge and judgment from the effects of natural earthquakes. In addition, new earthquakes were studied with particular reference to the nuclear program. These include Anchorage 1964 (1); New Mexico 1966 (2); Parkfield 1966 (3); Truckee 1966 (4); Colombia 1967 (5)(6) where the first strong motion record in South America was obtained as a result of this program; Borrego mountain 1968; Fairbanks 1969 (7); and San Fernando 1971 (8)(9)(10)(11). For the latter earthquake several special studies were conducted on both lowrise and highrise buildings. In more recent years the original situation has reversed -- information from the nuclear response program is now more complete and refined in many cases than from the earthquake field, and it indeed is flowing that way. Certainly a great deal more is to be learned from the detailed study of both nuclear seismology engineering and of natural earthquake response than from either alone.

HIGHLIGHTS OF THE STRUCTURAL RESPONSE PROGRAM

Buildings: Over 20 highrise buildings have been instrumented and the data analyzed for many nuclear tests. Meaningful data have been obtained from recorded peak lateral roof accelerations up to about 5%g which values approach the pre-1971 governing seismic code requirement of the Uniform Building Code, Zone 1. Some of the results pertaining to periods, period changes, damping, orbital motion, modal response and ground floor versus free-field motion have been published (12)(13)(14). Data has also been obtained for lowrise buildings, structures one or two stories high. For example, buildings in the area of the RULISON Event were surveyed by pre- and post-shot visual inspections. Recorded ground motion was correlated with observed damage (15)(16)(17)(18). A comparison was made between RULISON data and data obtained in Glendale, California due to the San Fernando earthquake. Data relating to lowrise structures has also been obtained from field tests (19) and laboratory tests.

Testing: Two four-story reinforced concrete frame test structures were constructed at the Nevada Test Site. Forced and free vibration tests have been conducted intermittently with alternative types of partitions. Response to over forty underground nuclear detonations has been recorded with peak amplitudes up to twice the calculated yield limits of the structures. The data obtained has made possible the measurement of periods and damping over a large range of amplitudes of motion; the measurement of effects of past response history and "aging" and the measurement of the contribution of nonstructural partitions (20)(21). Laboratory tests have been conducted with cyclic loading tests on several types of partitions generally found in highrise construction. Data was obtained that can be related to stiffness, damping, work capacity (energy absorption) and threshold of damage (22).

Procedures: Part of the work involves the development of the technology of damage prediction and procedures -- empirical, theoretical and combinations thereof, and deterministic and probabilistic -- to make rapid but reliable analyses and predictions of ground motion spectra and of response. Approximate methods are developed to conserve time on large projects (23)(24)(25)(26). The Spectral Matrix Method (SMM) of damage prediction (27) has been used successfully to estimate damage, if any, over whole cities, areas, even countries. It uses predicted response spectra. An Engineering Intensity Scale (EIS) has been proposed as a badly needed supplement to existing intensity scales which will also be useful in damage estimation (28).

Findings: Much has been learned and demonstrated in the NVOO structural response program including the following: (a) damping, periods and mode shapes can be determined from response to actual ground motion (13); damping although highly variable with building type and amplitude of motion averages about 5% of critical for highrise buildings (13) and 5% to 10% for most lowrise buildings (19); natural periods are constant in some buildings and vary in others with a tendency toward lengthening with time and/or motion (12)(20)(21); tall buildings tend to move in both horizontal axes and almost extreme amplitudes may occur simultaneously (12)(14); in Las Vegas essentially the same response spectra are obtained from ground level records of tall buildings as from nearby free-field records (12)(14); ground motion varies considerably even in a short distance in the same geologic setting (12); a few cycles of selected ground motion may produce similar spectra to an entire record and that this motion may be modeled as regular wave forms (29); many buildings behave essentially as cantilevers (24)(26); lowrise building damage is predicted better by the horizontal plane vector or envelope spectra than by the maximum spectra (18); many but not all lowrise buildings have much greater strength than the codes require (18); human threshold perception of long period motion has a mean of about 0.002g acceleration (30); and the fundamental mode is generally the most important mode in response.

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