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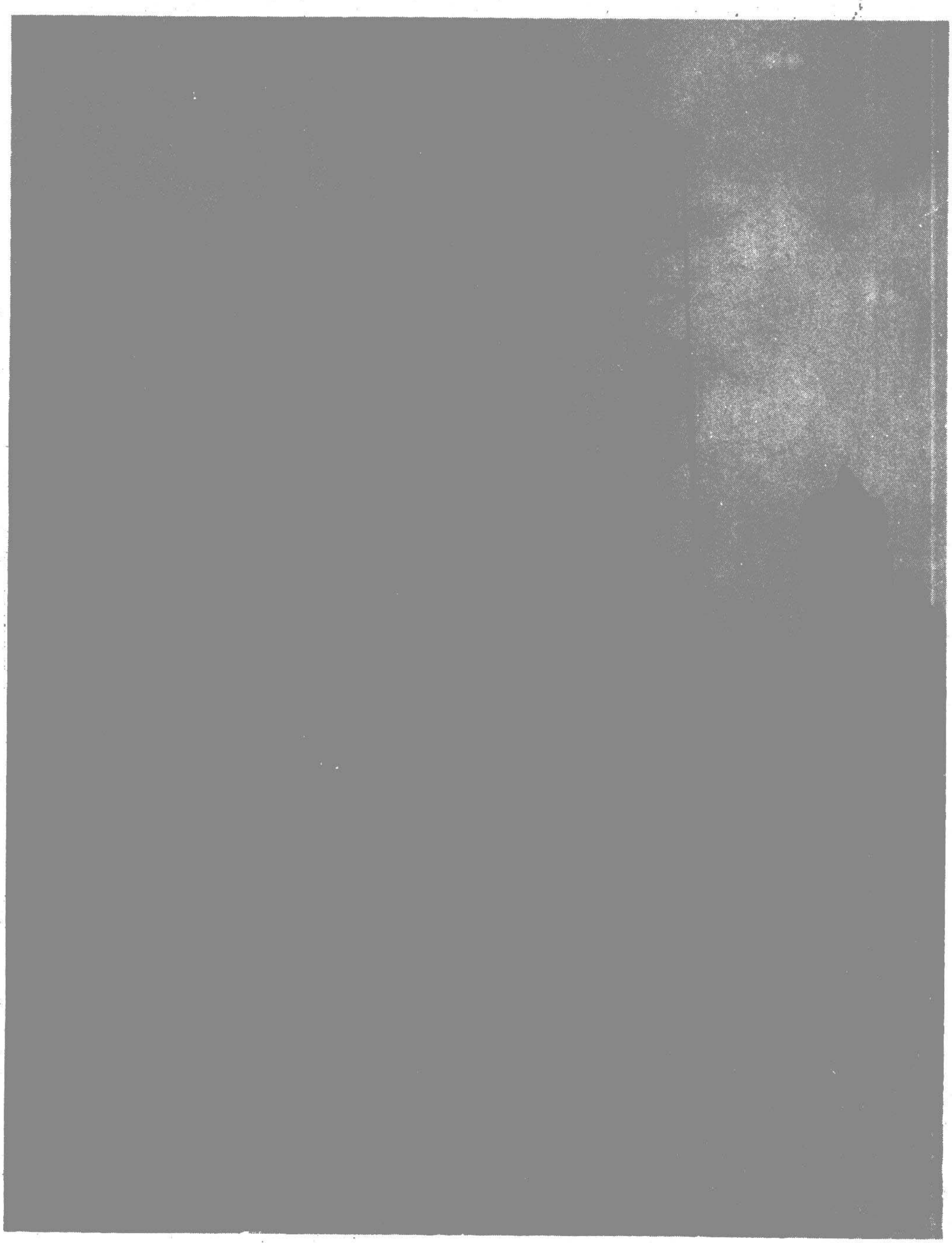
VOLUME IV — CONTENTS

* Presenting Author

6.2 Analytical Procedures *153*

6. RESPONSE OF STRUCTURES



New steel-frame buildings rise amid building rubble in San Francisco following the 1906 earthquake and fire. (From the files of H.J. Degenkolb)

6.1 Response Spectra and Input Motions

SCALING OF RESPONSE SPECTRA
AND ENERGY DISSIPATION IN SDOF SYSTEMS

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SUMMARY

This paper contains summaries of two studies recently completed at the University of Illinois, one on response spectra and one on energy absorption. Design spectra are commonly normalized by peak ground motions. In the current study alternative scaling factors were evaluated. It was found that a three parameter system of spectrum intensities may afford a better means for scaling spectra. The study on energy absorption focused on the total amount of energy imparted to a simple structure, and the dissipative mechanisms including the number of yield excursions and reversals. Also an effective motion criterion was identified.

SCALING METHODS FOR EARTHQUAKE RESPONSE SPECTRA

Introduction

Early recommendations for earthquake design spectra were published by Housner, and by Newmark and Hall. In 1973 the results of companion statistical studies by Newmark and Blume were reported, which together form the basis for much of the current design practice (Ref. 1). In current practice, the earthquake hazard at a site is characterized by estimates of the expected peak values of ground acceleration, velocity, and displacement. The corresponding design spectra are constructed by amplifying these ground motion maxima by appropriate factors determined from the previously reported statistical studies. In the roughly ten years since the development of these design procedures, two important observations have been made. First, from the statistical studies themselves, it has been noted that the dispersion or scatter in the data is large. For example, coefficients of variation exceeding 50 percent have resulted when spectra are normalized or scaled by peak ground motion values. Secondly, from observations following actual earthquakes, it has been noted that levels of damage are inconsistent with large ground motion maxima. That is, greater levels of damage might have been expected had the peak instrumental ground motions been known beforehand. Of course, these peak parameters convey little or no information regarding the earthquake duration and frequency content, two important elements

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affecting damage. The conclusion is that ground motion maxima, alone, are poor indicators of earthquake damage potential or earthquake strength.

The objective of this study (Ref. 2) is to evaluate the current practice of scaling earthquake response spectra by the three peak ground motions. Other investigators such as Mahin and Bertero have suggested such studies, and, Cornell, Banon, and Shakal have reported results in which response spectra were scaled by mean Fourier amplitudes of acceleration. In this study, alternative scaling techniques are investigated in greater detail than heretofore considered. The approach, simply stated, is to statistically evaluate normalizing factors which have been proposed over the years, with the goal of reducing (ideally, minimizing) the dispersion or scatter encountered in current scaling methods.

Statistical Evaluation

The normalizing factors considered in this study are categorized into two groups, one based on ground motion data and the other on response-related quantities. The parameters within the group based on recorded ground motions are the integrals of the squared ground motions, and the root-square, mean-square, and root-mean-square motions. Those in the response-related category include the spectrum intensity and the amplitudes of the Fourier spectrum of ground acceleration. A three-parameter system of spectrum intensities, computed from the 2 percent damped elastic pseudovelocity spectrum, is developed. The spectrum intensities are determined within low, intermediate, and high ranges of frequency, appropriately selected to provide the least average dispersion in the corresponding frequency regions of the elastic spectra. A similar set of three mean Fourier amplitudes is derived.

In the statistical analysis, spectra for elastic and inelastic systems, computed from an ensemble of 12 earthquake accelerograms, are considered. The group of ground motions was selected to encompass a wide variety of conditions such as geographical location, earthquake magnitude, epicentral distance, and amplitude and duration of strong shaking. The response spectra, computed for displacement ductilities of 1 (elastic), 1.5, 2, 3, 5, and 10 included those for elastoplastic systems with 2, 5, and 10 percent damping. Bilinear systems with 5 percent damping and 2, 5, and 10 percent strain-hardening were also considered.

Results

The results of the study of alternative scaling procedures for earthquake response spectra may be summarized as follows.

1. For elastic spectra, the root-square displacement offers moderate reductions in scatter compared with that which results from normalization by the peak ground displacement. In the low frequency region, between 0.07 and 0.2 HZ the root-square displacement provides, on the average, about a 30 percent decrease in the coefficient of variation for the normalized spectra.