Theme Report on Topic 2

GROUND MOTION, SEISMICITY, SEISMIC RISK AND ZONING

by

C. Allin Cornell[I]

INTRODUCTION

The nearly one hundred twenty accepted papers contributed to this theme testify to its importance, but they also will discourage all but the most dedicated reader (and your intrepid theme reporter) from reading each and every one in search of information of individual interest. The large number also renders their systematic review impossible. Therefore, a major goal of this report has been simply to make the papers more accessible to all by identifying for the readers those that relate strongly to a particular topic. See Table 1. The organization of those topics becomes, however, the reporter's personal interpretation of the most useful categorization of current research activities in the several fields covered by this theme, at least as these activities are represented by the contributions to this conference.

This last qualification must be made because, whereas this theme alone deals with the transition zone between earthquake engineering on one hand and the disciplines of seismology and geophysics on the other, it is not true that we have at this conference a representative review of current research in all the subject topics. Seismicity, for example, is covered by very few papers. Nonetheless, it is not the case that we have represented here only that research on these various topics that has been conducted by earthquake engineers; there is an encouraging representation of other disciplines among the authors. In fact, as will become evident, one outstanding characteristic of this Sixth Conference is that it illustrates the recent strong interest and developments in near-field (strong motion) geophysical theory and its application to earthquake engineering.

Because of the large sample size, it is hoped then that the reader of this summary report will gain an appreciation of current research emphases simply through the volume of contributions to each of the sub-topics. This is an objective measure. The more subjective position of the reporter will be apparent through selection of sub-topics onto which the indi-

I Professor of Civil Engineering, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

vidual contributions have been projected and through particular points in those papers that I have chosen to emphasize and reference individually. Unfortunately, my own background limits my ability to appreciate all of these sub-topics in the perspective they individually deserve. Therefore, I must apologize to the authors as a group if, in my subjective comments, emphases, and references, I have failed to treat evenly all the sub-topics of the theme. I am particularly concerned that many papers dealing specifically with both theoretical and empirical studies of the effects of local geological conditions on ground motions are not presented here in their proper perspective. I believe that they should better have been included in the Dynamics of Soils theme. Certainly, closely related papers are located in that theme, some perhaps that could benefit by comparison to the interesting empirical test results provided by many authors placed in this session.

GROUND MOTIONS

The study of earthquake ground motions is the predominant topic in this theme. Broadly speaking, the authors are concerned with describing earthquake motions and with predicting them. It is convenient to break the latter subject into three separable processes: source generation, propagation over a gross transmission path (one to tens of kilometers in length), and filtering by the local geological conditions (tens to hundreds of meters in dimension).

Several general observations apply to all these topics. First, we are beginning to witness the effects of an enormous increase both in the number of strong motions records and in their availability. Many of the papers use large numbers of records to check or calibrate their results. Many of these records have been extensively processed by the authors (e.g., we find empirically fit attenuation laws for spectral ordinates of non-linear dynamic systems (62*)). A significant number of papers use only the many records from the 1971 San Fernando earthquake (e.g., 5, 9, 10, 22, 26, 57, 107, etc.).

Secondly, but not independently, we find at this conference a large number and variety of empirical statistical analyses of ground motion properties and their dependence on magnitude, epicentral distance, etc. It is fortunate now to have the large numbers of samples to make these procedures effective. Unfortunately, however, there is as yet very little apparent critical evaluation of the records to be included in the sample, of the biases implicit in the strong-motion-data collection process, or of the appropriateness of the statis-

*Numbers refer to papers of this theme as listed in Table II.

tical tools being used. For example, it is probable (owing to the nature of earthquakes and of accelerometer networks) that virtually every data set used here for statistical studies of strong motion parameters would exhibit a strong positive correlation between the magnitudes and distances. This fact alone could cause a (possibly wholly spurious) positive correlation between duration and distance. (A more appropriate measure would be the partial correlation coefficient between duration and distance for fixed magnitude.)

Thirdly, and again not wholly independently of the growing number of strong motion records, we can witness at this conference the benefits of a new, strong geophysical interest in theoretical source modeling for the prediciton of near-source, higher frequency motions (e.g., 33, 38, 59, 77, 95). Empirical earthquake engineering studies are beginning to use parameters (e.g., stress drop, seismic moment, etc.) and functional forms suggested by more recent geophysical studies (e.g., 9, 13, 42, 106). Near-source motion studies are currently a popular topic in geophysics, but it remains true that records most suitable for such studies are rare (35).

Ground Motion Descriptions There is still in engineering a strong interest in developing improved parameters and methods for analyzing and representing earthquake motions.

The simplest but most important class of parameters remains that of intensity parameters. It is most desirable for many engineering purposes to have a single, scalar parameter to define the strength of a motion. It is difficult, for example, to make probabilistic seismic hazard assessments for other than scalar descriptors of motions. At the same time the parameter should be a good predictor of engineering effects (e.g., peak structural response or damage). To make best use of historical seismicity information the parameter should also be well correlated with the popular non-instrumental intensity scales. Several new scalar intensity measures are proposed at this conference (26, 78, 87).

There are also several studies providing hard statistical evidence on more conventional intensity measures (peak acceleration (44, 63), Modified Mercalli and MKS Intensity (103, 109), Arias intensity (26, 112), etc.) and on the correlation between these measures. The standard deviations of the prediction residuals are generally discouragingly large (70% or more), a fact engineers should deal with explicitly when faced with the need to predict one intensity from a value of the other.

Fresh techniques for studying and characterizing strong ground motion are displayed by the authors. There is a commonly expressed concern that motion duration with its potential influence on damage is not sufficiently well represented in the most familiar procedures, including elastic response spectra (e.g., 26, 62, 70, 87). In fact, the new scalar intensity proposals referred to above are generally responding to this concern with duration. Several authors use the response of inelastic systems as a vehicle for analysis of strong motions (e.g., 21, 37, 47, 62, 104). At least one, McGuire (62), concludes, however, that the elastic spectral ordinate (but not the peak acceleration) does in fact correlate strongly with damage (as represented by the hysteretic energy absorbed by a non-linear oscillator).

Other examples of relatively uncommon studies of motion properties include:two-dimensional response spectra (54), three-dimensional correlation, analyses (15, 57, 112), time variation of the frequency content (41, 56), etc. The installation of spatial arrays of strong motion instruments (both vertically and horizontally) has begun to yield important information about spatial correlation and the effects of logical geological features (e.g., 4, 28, 80, 105, 110). This conference also shows a heightened interest in longer period motions (2 to 10 seconds) (e.g., 28, 33, 91, 105).

Finally, the authors have contributed a number of papers on the characteristics of motions from specific earthquakes (including the great 1755 Lisbon earthquake (43) and specific regions (e.g., 2, 36, 52, 86, 112, etc.). Several papers deal with mathematical modeling (21, 50) and simulation of motions. Methods are presented which include time-varying frequency content (57, 69) and vector-valued processes (6). Again, non-linear structural behavior is a common concern (21, 47, 69).

<u>Dependence of Ground Motions on Source and on Gross Propagation Path</u> Both empirical and theoretical studies of source and path influences are represented in the conference. As mentioned above, empirical, statistical studies are bountiful. More than fifteen papers deal with regressions of scalar intensity parameters on distance and magnitude. (See Table I.) A full summary paper is needed simply to compare and contrast their results. Even so, Hudson (35) points out that for the very near source (i.e., within a distance comparable to the source dimensions) data remain very scarce and yield no obvious trends.

Other basically empirical studies of this style include several papers on duration dependence on magnitude and distance (20, 44, 98, 112, 116). The definition of duration due to Trifunac and Brady (109) is the most common. Other dependent variables in these regressions include "predominant periods", the ratio of vertical to horizontal peak accelerations, etc.

In a few cases the independent variables studied include azimuth (5) or other parameters. But after distance and then magnitude (several studies focus on San Fernando data only and hence show only distance dependence), the most popular independent variable is (gross) soil type (e.g., hard versus soft). This variable will be discussed below.

Finally, a popular subject and a fresh topic for empirical attenuation studies was spectral content. (See Table I.) Direct knowledge of the dependence of Fourier spectral ordinates and linear or non-linear response spectral ordinates on magnitude and/or distance makes it possible to avoid the conventional two-step approach (e.g., (a) predict peak acceleration from given magnitude and distance and (b) predict oscillator response from the peak acceleration).

Papers on theoretical studies of strong ground motion represent, as mentioned above, a strengthening trend. The topic can be separated generally into source and path effects (13). The most prevalent current activities in the former area are the specification and analysis of proposed source models (this is usually a kinematic model in which a displacement time-space function is specified at the source (33, 38, 59, 77), but models specifying stress time-space functions (95) appear to be becoming more common also). Most of the models' parameters are inferred indirectly from measured motions. One difficulty is lack of uniqueness in such inferences. Another problem of particular concern to earthquake engineering is that the motions in the high frequency region of most common practical interest (say, above 0.5 hertz) are sensitive to the finer details of these models. Most such studies treat only body waves.

The concern with the propagation of waves is often split into the longer distance, transmission path and the path through geological features local to the site. The theoretical studies of propagation through random media (48, 55) and through layered media (12, 72, 77) have application to both problems, but the former are perhaps especially appropriate in the longer transmission path problem where the paths are more complex, and the latter are more suited to the near-site problem. The study of surface waves requires a half-space model, preferably involving layered media (77) for the analysis of the entire path.

<u>Dependence of Ground Motions on Local Geological Conditions</u>
Again, empirical studies outnumber the theoretical. A large

number of the empirical papers have as their objective, however, verification of theoretical analyses of the influence of local soil conditions on ground motions.

A significant number of papers involve large-data-set statistical analyses of the effect of soils. (See Table I.) Soil conditions are typically entered as one independent variable in a generalized least squares analysis. The soils categorization is necessarily crude (e.g., soft, intermediate, hard; or depth to rock) and the number of hard or rock sites is usually limited. Often the question asked is simply: is there a statistically significant difference at hard and soft sites between the results (e.g., the peak ground acceleration versus magnitude and distance, the duration (116), the relationship between peak acceleration and M. M. Intensity (63), etc.). The results are generally positive; exceptions include the ratio of vertical to horizontal peak accelerations (115).

Another class of observed ground motion papers aims at a more detailed representation of the soil effects, specifically frequency-dependent influences. These studies include the use of strong ground motions, microtremors (45, 83, 101), aftershocks (25, 34), and explosions (89, 93) to infer the filtering effects of specific sites. The results are in some cases (4, 80, 101) compared with analytical predictions (usually one-dimensional soil column models). The difficulties with these approaches are outlined by Trifunac (111). Berrill (9) concludes from a large sample of San Fernando sites that soil influence is not as strong as many engineers believe. The data from new horizontal and vertical arrays of instruments (4, 28, 40, 80, 105, 110) are especially welcome additions.

The papers on theoretical analysis of local geological effects should, of course, be considered in conjunction with those submitted to the Dynamics of Soils theme at this conference. Included in this Ground Motion theme are papers on such matters as surface waves in layered media (64, 77, 93), elasto-plastic surface layers (32), two-dimensional models (108, 118), and the dependence on angle of wave incidence (12).

SEISMICITY

With the exception of seismic hazard analyses (to be discussed below) there were simply relatively few papers submitted to the conference on seismicity <u>per se</u>. Future conference organizers would do well in the reporter's opinion to invite one or more general reports on this subject to keep the earthquake engineering audience informed of advances in this closely coupled field. The appropriate level of confidence on seismologists' input into engineering studies must be developed by the responsible decision makers.

The majority of the papers here deal with seismicity studies of specific regions (3, 16, 30, 46, 65, 66, 99). Three consider more general subjects. Wallace (114) uses observations of fault scarps and fault traces to infer average activity rates of large events and maximum magnitudes over several thousand years in the past. The potential benefits of such an enlarged data base are most important. Cummings and Leeds (18) introduce the use of classical solid mechanics to predict zones of high stress and potential future epicenters. Cluff et al (16) look at the surface fault hazard in Managua and propose a generalized approach to preparing fault hazard maps and zoning codes.

SEISMIC RISK AND ZONING

Let us define seismic hazard analysis (SHA) as the development of a probability versus ground motion intensity curve for a site (or set sites to produce a map). It has been used as a macro-zoning tool. Modification of such zones to reflect local soil conditions is referred to as micro-zoning. We have already discussed most of the materials relative to the latter process that were submitted to this theme (see also the Dynamics of Soils theme).

Seismic Hazard Analysis This conference has seen a large increase in the number of papers on this topic. They include both specific applications and methodology.

The applications are to the city of Osaka (113), the Caracas Valley (1), Southern California (23), and the countries of India (7, 58, 88), Canada (68), Iran (76), Nicaragua (92), and the U.S. (117). The readers are invited to compare these studies for similarities and differences in general methodology (empirical versus analytical), in factors included or excluded (e.g., upper bounds on magnitudes, dispersion about attenuation correlations, etc.),and in procedures used to estimate parameters. In one case evidence is presented to permit comparison of the estimates made by two different Indian investigators by quite different methods (7, 58). A check at one point shows one investigator estimates the annual probability of exceeding 0.10g is 0.02, whereas the other estimates a 0.01 probability of exceeding 0.08g. The reporter's experience is that these are reasonably close comparisons for this probability level.

The papers on methodology include general outlines (82, 111), a suggestion for assessing subjective probabilities (74), and proposals that extend hazard analyses to include additional factors. The last include local soil effects (23, 27) which implies that macro- and micro-zoning become one. Other extensions are the use of a response parameter rather than an intensity parameter (62), the analysis of ground failure hazards (liquefaction (17) and surface rupture (84)), and the consideration of spatially extended "targets" such as lifelines (71, 82).

Seismic Risk Analysis This title refers to the prediction of expected economic and other impacts due to future earthquakes. Generally, it incorporates both the environmental threat (Seismic Hazard Analysis) and the losses associated with given levels of earthquake intensity. Two papers here present the overall analysis (24, 85) whereas several deal with various aspects of loss estimation or impact prediction (10, 19, 81, 100). In one interesting case (81) the concern is with the correlation between intensity and human behavior.

Zoning Five conference papers address themselves explicitly to the general issues and difficulties of microzonation (16, 67, 78, 102, 111). All agree as to its importance, but they also generally concur on the weakness of current methods and data.

******

The reporter would like to thank all the authors in the Ground Motion, Seismicity,Seismic Risk and Zoning Theme for their contributions.

TABLE I

PAPERS RELATED TO OUTLINE TOPICS

(Numbers correspond to the paper list by author, Table II)

I. GROUND MOTIONS

1. Descriptions, Properties, Classifications, Models

   a. Measures of Intensity:
      (Relationships among current measures; new proposals)
      26, 39, 44, 63, 70, 78, 87, 97, 103, 109, 112

   b. Observed Properties:
      (General characteristics of motions; methods for exposing and displaying properties; motion characteristic of specific events or specific regions)
      2, 4, 15, 35, 36, 37, 41, 43, 44, 49, 52, 54, 56, 57, 60, 73, 80, 86, 91, 105, 110, 112, 115

   c. Models of Motions:
      (Simulation methods)
      21, 47, 50, 56, 57, 69, 104

2. Dependence of Ground Motions on Source and Gross Propagation Path

   a. Empirical Dependence of Conventional Intensity Parameters
      (Regressions of peak acceleration, etc., on magnitude and distance)
      8, 10, 11, 14, 22, 26, 31, 35, 44, 63, 68, 79, 94, 96, 98, 106, 112

   b. Empirical Dependence of Other Parameters
      (i) Duration: 20, 44, 98, 112, 116
      (ii) Others (new intensity measures, ratio of vertical to horizontal intensity, dominant periods, etc.): 44, 62, 90, 109, 112

   c. Empirical Dependence of Relative Spectral Content
      (Fourier, power, and linear and non-linear response spectral ordinates, a/v ratio, etc.)
      5, 9, 14, 31, 44, 53, 112, 116

   d. Theoretical Considerations: Source and Path Effects
      (Near-field motions predicted from source-mechanism models, propagation through random media, etc.)
      12, 13, 33, 35, 38, 42, 48, 55, 59, 72, 77, 95, 106

3. Dependence of Ground Motions on Local Geological (Soil) Conditions

   a. Empirical Dependence of Intensity on Gross Soil Categorizations

(Influence of "rock" vs. "soil" on common intensity regressions; also on duration, on the ratio of vertical to horizontal intensity, etc.)
5, 11, 14, 20, 22, 63, 96, 115, 116

b. Dependence of Intensity and Spectral Characteristics at Specific Sites
(Based on strong motions, aftershocks, microtremors, empirical, empirical vs. theoretical, etc.)
(i) Surface Measurements Only: 5, 9, 22, 25, 45, 53, 78, 79, 83, 89, 91, 93, 101, 107
(ii) Simultaneous Surface and At-Depth Measurements: 4, 28, 40, 80, 105, 110

c. Theoretical Considerations: Local Propagation Path
(One-dimensional layered media, higher dimensional cases, influence surface waves, physical models, etc.)
12, 32, 61, 64, 77, 93, 101, 108, 118

II. SEISMICITY

1. Seismicity of Specific Regions
3, 16, 30, 46, 65, 66, 99

2. More General Considerations
16, 18, 114

III. SEISMIC RISK AND ZONING

1. Seismic Hazard Analysis (Environmental Threat)
(Statistical and probabilistic approaches to intensity vs. annual probability of occurrence, etc.)

a. Applications to Specific Sites or Regions
1, 7, 23, 48, 51, 58, 76, 88, 92, 113, 117

b. Methodology
7, 17, 23, 27, 62, 71, 74, 82, 84, 111, 113

2. Seismic Risk Analysis (Environmental Threat plus Items Threatened)
(Expected future loss calculation, loss estimation, impact estimation, etc.)
10, 19, 24, 81, 85, 100

3. Zoning
(Considered broadly; see also Dependence of Ground Motion on Local Geological (Soil) Conditions)
16, 65, 102, 111

TABLE II

PAPERS ON THE THEME: GROUND MOTIONS, SEISMICITY, SEISMIC RISK, AND ZONING

Note: Papers are listed here only for ease in reference in the Summary Report. Papers are listed in alphabetical order; first author only is given (unless more authors and/or titles are needed to distinguish among several papers by the same author.) When titles are used, articles such as "the" and "an" are dropped. Papers underlined are of type "A".

Serial Number	Author(s)	Preprint Page
1	Alonso, J.L.	2-419
2	Amin, M.	2-552
3	Ansari, A.R.	2-485
4	Arai, H.	2-167
5	Arnold, P.	2-113
6	St. Balan	2-185
7	Basu, S.	2-425
8	Bernreuter, D.L.	2-09
9	Berrill, J.B.	2-101
10	Blume, J.A. "Engineering..."	2-375
11	Blume, J.A. "Sam..."	2-87
12	Borcherdt, R.D.	2-255
13	Campbell, K.W.	2-51
14	Chandra, B.	2-518
15	Chen, C.	2-524
16	Cluff, L.S.	2-455
17	Crouse, C.B.	
18	Cummings, D.	2-475
19	Deza, E.	2-540
20	Dobry, R.	2-131
21	Drenick, R.F.	
22	Duke, C.M.	2-93
23	Eguchi, R.T.	2-399
24	Eisenberg, J.M.	
25	Espinosa, A.F.; Husid, R.	2-522
26	Espinosa, A.F.; Lopez-Arroyo, A.	2-367
27	Faccioli, E.	2-243
28	Fujiwara, T.	2-69
29	Gates, G.O.	2-529
30	Grasse, J.	