Proceedings from the Site Effects Workshop

Hosted and Supported by the
National Center for Earthquake Engineering Research
State University of New York at Buffalo
Buffalo, New York
on
October 24-25, 1991

Technical Report NCEER-92-0006

Edited by: Robert V. Whitman[1]
February 29, 1992

NCEER Project Number 90-6002

NSF Master Contract Number BCS 90-25010
and
NYSSTF Grant Number EC-91029

[1] Professor, Department of Civil Engineering, Massachusetts Institute of Technology

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
State University of New York at Buffalo
Red Jacket Quadrangle, Buffalo, NY 14261

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NCEER-92-0006	2.	3. PB92-197201

4. Title and Subtitle
Proceedings from the Site Effects Workshop
October 24-25, 1991

5. Report Date
February 29, 1992

6.

7. Author(s)
Robert V. Whitman

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Department of Civil Engineering
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA. 02139

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) BCS 90-25010
(G) NYSSTF Grant No. EC-91029

12. Sponsoring Organization Name and Address
National Center for Earthquake Engineering Research
State University of New York at Buffalo
Red Jacket Quadrangle
Buffalo, N.Y. 14261

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes
This workshop was partially supported by the National Science Foundation under Grant No. BCS 90-25010 and the New York Science and Technology Foundation under Grant No. NEC-91029.

16. Abstract (Limit: 200 words)
This report presents some of the conclusions reached and recommendations made at the Site Effects Workshop held at the State University of New York at Buffalo, October 24-25, 1991. Those attending the conference discussed specific recommendations to be made concerning 1) desirable, near-term changes to building code provisions with regard to the categorization of local site conditions and 2) directions for further research leading to more realistic code site-categories in the long-term. Participants addressed the adequacy of existing code formats with respect to site categories and soil factors. They considered the definition of sites by site period instead of code-defined site category. The report also presents recommendations for the use of time history inputs for site-specific design and concludes by calling for: 1) more quantitative descriptions, in terms of soil stiffness and depth of soil strata, of the site categories commonly used in the U.S.; 2) additional site categories representing rocks of differing stiffness; and 3) soil factors that incorporate intensity of ground shaking, impedance contrast between soil column and bedrock, and perhaps source characteristics as well. Appendices include excerpts from French and Greek codes, a list of participants, questionnaire results, some analytical results, etc.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

CODE PROVISIONS.
SITE CATEGORIES.
UNITED STATES.

CODE DEVELOPMENT.
SOIL FACTORS.
SOIL DYNAMICS.

LOCAL SITE CONDITIONS.
BUILDING CODES.
EARTHQUAKE ENGINEERING.

c. COSATI Field/Group

18. Availability Statement Release Unlimited	19. Security Class (This Report) Unclassified	21. No. of Pages 84
	20. Security Class (This Page) Unclassified	22. Price

PREFACE

The Site Effects Workshop is the third in a series of NCEER Workshops which deal with ground motion aspects of building code provisions. The first (Whitman, 1989) dealt with the question of what ground motion parameters to map. Recommendations ranged from mapping spectral ordinates for the near-term to the far-term possibility of mapping parameters identifying the appropriate features of motion time-series. The second (Whitman, 1990) considered the question: For what reference site condition should ground motion parameters be mapped? Use of the S2 site was recommended. The results of both Workshops influenced the maps recently prepared by Algermissen and colleagues of the USGS. These maps appear in appendix to the commentary of the **1991 Revision of the NEHRP-Recommended Provisions**.

The timing of this Workshop is particularly appropriate. The Structural Engineers Association of California (SEAOC) has recently made plans for a major effort to review many of these issues. The Building Seismic Safety Council (BSSC) is now beginning a cycle of effort leading up to the 1994 revision of the NEHRP Recommended Provisions - with the initial expectation of suggesting major changes in the way in which lateral forces are to be determined. Studies are underway at several organizations, and NCEER is initiating a research study into these matters. The recommendations developed by the Workshop can be expected to have significant influence on these various near-term efforts.

The participants in the Workshop were primarily geotechnical engineers, with a few (and definitely non-token) with seismological or geophysical background. The greatest number were from California, but there was strong representation from the Pacific Northwest, Salt Lake City, the mid-continent and the Northeast. Many participants will be involved with either or both of the SEAOC and BSSC efforts.

The Workshop was made possible by funding provided by NCEER. The role of the Organizer was to identify participants, to prepare background information as a basis for discussion at the Workshop, and to guide the effort during the Workshop.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1
INTRODUCTION

This subject matter of this Workshop was site effects provisions for building codes. The purpose was to develop specific recommendations concerning:

1. Desirable changes to building code provisions in the near-term.
2. Directions for research and further study to provide the basis for possible more profound changes in the far-term.

The Workshop was held on the campus of the State University of New York at Buffalo, and was hosted by the National Center for Earthquake Engineering Research. A list of attendees appears in Appendix A, and the initial agenda is reproduced in Appendix B. There were no formal presentations or written papers, rather, invited attendees participated in focused discussion which led to the formulation of conclusions and recommendations.

SECTION 2
BACKGROUND

In current versions of the several model building codes, and in state and local building codes based upon them, site effects are accounted for through four soil factors that modify the base shears (and hence forces in structural members) required for design. Figures 2-1 and 2-2 reproduce the descriptions of the four site conditions, as set forth in the 1991 Revision of the Uniform Building Code (ICBO, 1991) and in the 1988 Revision of the NEHRP-Recommended Provisions developed by the Building Seismic Safety Council (Federal Emergency Management Agency, 1988). This basic format was developed as part of the ATC-3 study in the early 1970's, which laid the basis for the current versions of codes. The ATC-3 report (Applied Technology Council, 1978) recommended 3 site conditions. The S4 site condition was added in the late 1980's following the experiences in Mexico City during the earthquake of 1985. (Incidentally, the original proposal made during the ATC-3 study called for a fourth site category - rock - which presumably would have had a site factor less than one. This final category was dropped from the final ATC-3 recommendations, as adding too much complexity.

During the decade prior to the ATC-3 study, site effects had been represented in model and actual codes by expression involving the period of the site. The maximum soil factor was tied to the stiffness of the near surface soils, with a maximum value of 1.5 in the case of soft soils. This approach was abandoned because of difficulties in establishing agreed-upon, standard procedures for evaluating the site period. In addition, the site information necessary for such a calculation generally would not be available. Indeed, there was controversy as to whether the concept for a site period was actually valid. Many other countries of the world do employ site period in evaluating site effects in their codes.

FIGURE 2-1 Table No. 23-J Site Coefficients

(Reproduced from the 1988 edition of the Uniform Building Code, copyright © 1988, with the permission of the publishers, the International Conference of Building Officials).

TABLE NO. 23-J
SITE COEFFICIENTS[1]

TYPE	DESCRIPTION	*S* FACTOR
S_1	A soil profile with either: (a) A rock-like material characterized by a shear-wave velocity greater than 2,500 feet per second or by other suitable means of classification, or (b) Stiff or dense soil condition where the soil depth is less than 200 feet.	1.0
S_2	A soil profile with dense or stiff soil conditions, where the soil depth exceeds 200 feet.	1.2
S_3	A soil profile 40 feet or more in depth and containing more than 20 feet of soft to medium stiff clay but not more than 40 feet of soft clay.	1.5
S_4	A soil profile containing more than 40 feet of soft clay.	2.0

[1] The site factor shall be established from properly substantiated geotechnical data. In locations where the soil properties are not known in sufficient detail to determine the soil profile type, soil profile S_3 shall be used. Soil profile S_4 need not be assumed unless the building official determines the soil profile S_4 may be present at the site, or in the event that soil profile S_4 is established by geotechnical data.

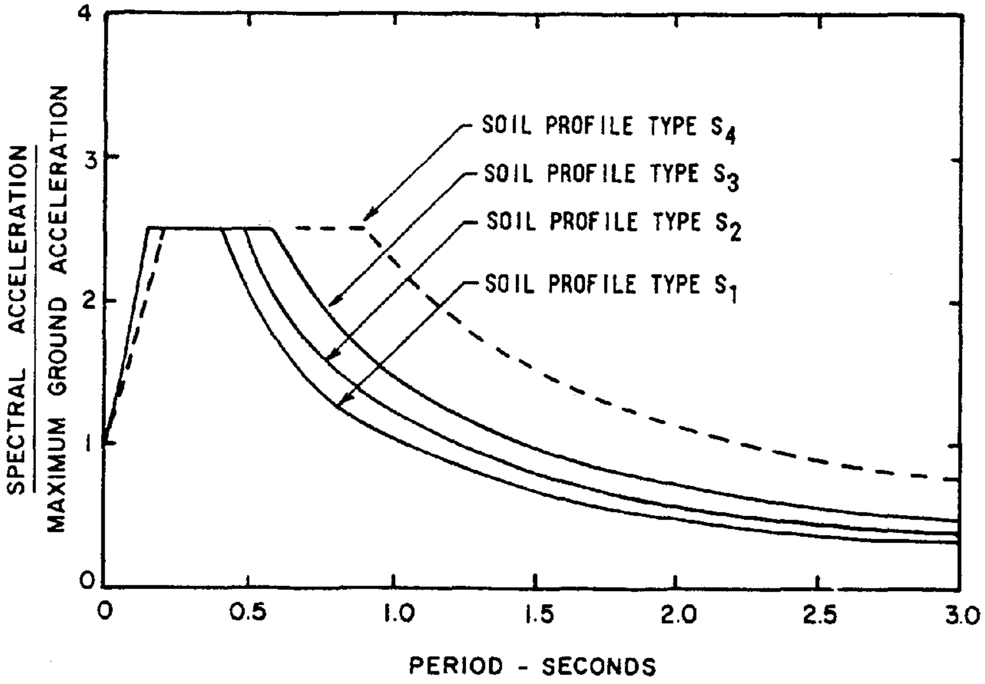
FIGURE 2-2 Normalized Response Spectra Recommended for use in Building Codes *(from NEHRP '88)*

- Soil Profile Type S_1 - Rock of any characteristic, either shale-like or crystalline in nature (such material may be characterized by a shear wave velocity greater than 2,500 feet per second), or stiff soil conditions where the soil depth is less than 200 feet and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.

- Soil Profile Type S_2 - Deep cohesionless or stiff clay soil conditions, including sites where the soil depth exceeds 200 feet and the soil types overlying rock are stable deposits of sands, gravels, or stiff clays.

- Soil Profile Type S_3 - Soft-to-medium stiff clays and sands characterized by 30 feet or more of soft- to medium-stiff clay with or without intervening layers of sand or other cohesionless soils.

- Soil Profile Type S_4 - Soft clays or silts greater than 70 feet in depth and characterized by a shear wave velocity of less than 400 feet per second.



The second Workshop recommended that site condition S2 be used as the standard reference site for mapping of ground motion parameters together with the present format of seismic provisions in building codes. That is to say, maps should give ground motion parameters applicable to an S2 site, and codes should then provide soil factors to adjust the parameters for other site conditions. Choice of a standard reference site proved difficult. Major considerations were: (a) the S2 site condition is encountered widely throughout the country, and (b) there was solid data for ground motions atop S2 sites in the Western United States. However, it was not clear that ground motion data for different site conditions were entirely consistent with the standard factors for adjusting among site conditions. It was generally felt that the theoretical and empirical bases for these adjustment factors should be given careful review.

During recent years, there have been a number of expressed concerns about the present code language dealing with site effects. There have been a number of complaints concerning current provisions, ranging from (a) improper soil factor values, to (b) difficulties in classifying sites according to present categories, to (c) failure to consider fundamental aspects, such as high impedance contrast between soil and underlying rock, to (d) inability of current provisions to account for factors such as duration. As one example of these difficulties, much of Boston and its surrounding area is underlain by a deep deposit of clay. On the basis of shear strength, the clay is borderline between being "soft" and "medium", and usually falls just above this threshold. The depth of the clay commonly is somewhat less than 200 feet. Thus sites in Boston often are classified as S1 sites, despite evidence from past earthquake experiences that ground motions have been strengthened by this clay.

In preparation for this Workshop, the questionnaire appearing in Appendix C was circulated among experienced geotechnical engineers. One question asked about the difficulty in applying the current provisions concerned perceived shortcomings to the present provisions. Figure 2-3 is a summary of responses. Another question inquired as to changes that should be made in current provisions. Figure 2-4 lists the responses.

A major review of site classification and site factors was made in connection with drafting proposed seismic provisions for the building code of New York City (Jacob, 1990). Two specific proposals were made for site category descriptions and soil factors that differed from those in current model codes.

1. Figure 2-5 is a list of proposed site categories together with soil factors. There are more categories, and soil factors range from 2/3 to 2.5 - a span of nearly a factor of 4 (as contrasted to a range of 2 in current codes). It was argued that a greater span is required for sites with underlying hard rock (with shear wave velocities on the order of 9,000 ft./sec., typical of many parts in the Northeast) than for sites with underlying soft rock. This is because of the greater impedance mismatch -and hence less "radiation damping" - where the underlying formation is hard rock. The tables in Figure 2-6 compare proposed and conventional soil factors.

2. A set of quantitative descriptions was prepared for each of the site categories. An early version appears in Figure 2-7. These descriptions used quantities familiar to geotechnical engineers - blow counts and shear wave velocities. Different combinations of depth and stiffness of soil were provided for site categories; that is, rigid specifications of depths (such as 40 feet or 200 feet) were avoided. Thus, while site period was not specifically mentioned, the role of site period was accounted for implicitly. The terminology in the site category descriptions was also tied to specific definitions of soil and rock type used in the New York City building code.

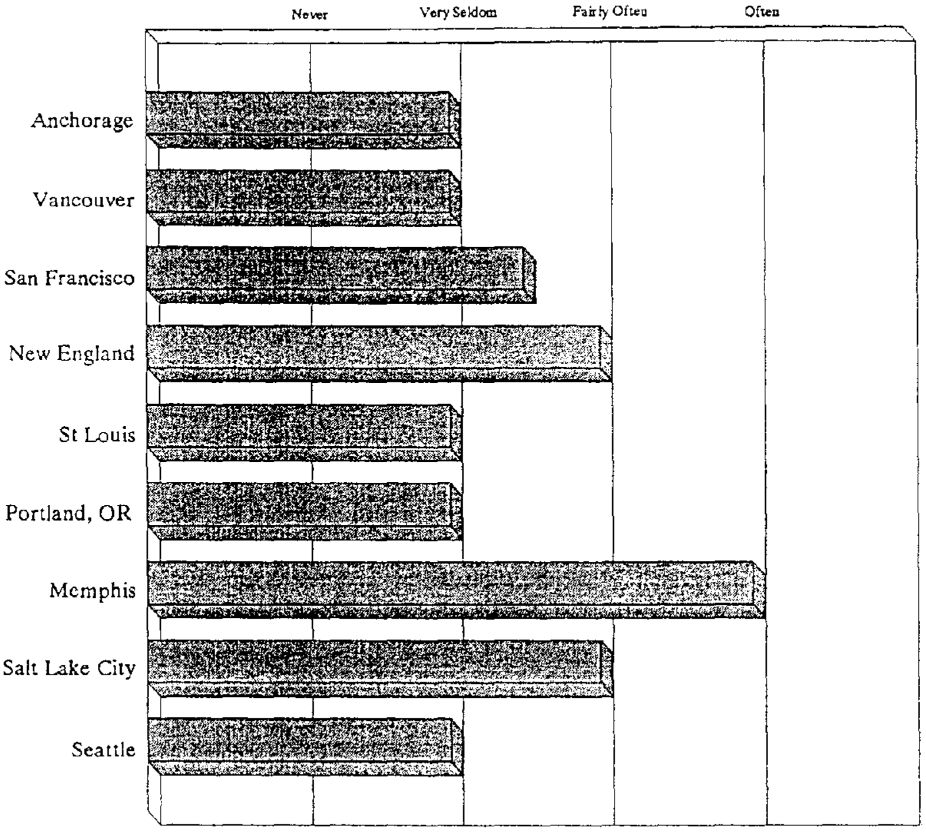
The expanded set of site categories (Figure 2-5) was retained in the final version of the proposed seismic provisions, and blow counts were kept as partial quantitative descriptors. However, the extended quantitative descriptions (Figure 2-7) were dropped.

Responses to the questionnaires also provided soil profiles typical for several metropolitan areas. Analyses using the computer program SHAKE have been performed at MIT, using input ground motions deemed reasonable for the respective area. Response spectra computed for ground surface have been compared with the design spectra specified by several different model codes. The results available by the time of the workshop (see Appendix D) were made available to participants in the Workshop, to assist in the discussions. A more complete set of results, and a discussion of their implications, will appear in a thesis by Jonathan Taylor (Taylor, 1992).

Some of the above-discussed difficulties and shortcomings can be addressed by relatively simple code changes in the near-term. Developing solutions to others will require further study and research. The Workshop strives to produce specific recommendations for both near-term changes and necessary additional research. Among the questions to be considered are: Do we now have the proper standard site categories? - or should there be more?, ... different?, ...described differently? ..have different site factors?; Should we be moving toward an entirely different approach - such as returning to site period as a key parameter? Looking further in the future, how will we deal with site considerations when there is increasing use of dynamic analysis with time-history of motion as input-and should there be topographic site factors?

FIGURE 2-3 Results of Site Categories Questionnaire, Page 2 of 5

Q. How Often Are Problems Encountered in Assigning Sites to Site Categories ?



Q. What Types of Sites Cause Difficulties ?

- Very deep but stable deposits, such as stiff alluvium, which can be classified as S2 or S3, or hard glacial till or residual soils which can be S1 or S2
- Some sand deposits which may be prone to liquefaction and are strictly not classified as S3 or S4
- Sites with variable layering, particularly unstable soft deposits interbedded with stiffer layers
- Soft relatively unstable deposits underlain by very deep stiffer material

FIGURE 2-4 Results of Site Categories Questionnaire, Page 4 of 5

Q. Can You Suggest Better Definitions for Standard Site Categories?

- The soil period could be incorporated into the construction of response spectra
- Profiles could be a function of shear wave velocity, depth and velocity contrast
- Clearer definitions of loose, stiff etc. are required, possibly by using SPT N60
- There could be a separate category for rock instead of including it with shallow stiff soils
- The S2 site category should have an upper limit of the soil profile depth
- The definition for clay in S4 should include a plasticity index or factor
- S4 should be changed to include thickness of clay > 10 feet
- S5 could be added to include Clay thickness > 40 feet
- Soft clay in S4 should have shear wave velocity defined between 200 and 250 fps, instead of 500 fps as currently
- The confusion arising from different definitions in different codes needs to be cleared up
- The site category could be tied to peak bedrock acceleration as well as to soil type and thickness
- Since amplification is non-linear in zones of high seismicity (high pga), and soft sites attenuate or "limit" accelerations, simple rules for limiting pga as a function of soil strength could be introduced

Q. Are the Relative Soil Factors for Current Categories Reasonable ?

- The current ratios are satisfactory
- The response spectrum shape should be included instead of just a factor
- For the eastern US, the peak ground acceleration is evaluated for hard rock condition while site categories use soft rock as reference site.
- The factor for rock is probably too high in the longer period range, because it is lumped in with shallow stiff soils
- There is a lot of uncertainty about the factors for soft soil sites, S3 and S4, and these should be revised as more information becomes available
- The current ratios for S4, particularly in the 0.5 to 2.0 second period range, underestimate spectral accelerations, which may provide a dis-incentive to carry out site specific response analyses.
- The factor for S4 should be increased to 2.5

FIGURE 2-5 Table A-1: Site Coefficients

(Currently proposed version for the NYCBC)

Type	Description	S-Factor
So:	A profile of Rock materials of class 1-65 to 3-65	**2/3**
S1:	A soil profile with either: (a) Soft Rock (4-65) or Hardpan (5-65) or similar material characterized by shear wave velocities greater than 2500 fps, or (b) Medium Compact to Compact Sands (7-65) and Gravels (6-65) or Hard Clays (9-65), where the soil depth is less than 100 feet.	**1.0**
S2:	A soil profile with Medium Compact to Compact Sands (7-65) and Gravels (6-65) or Hard Clays (9-65), where the soil depth exceeds 100 feet.	**1.2**
S3	A total depth of overburden of 75 feet or more **and** containing: more than 20 feet of Soft to Medium Clays (9-65) or Loose Sands (7-65, 8-65) and Silts (10-65), but not more than 40 feet of Soft Clay or Loose Sands and Silts.	**1.5**
S4:	A soil profile containing more than 40 feet of Soft Clays (9-65) or Loose Sands (7-65, 8-65), Silts (10-65) or Uncontrolled Fills (11-65), where the shear-wave velocity is less than 500 feet per second.	**2.5**

Notes to Table A-1:

1. The site S Type and corresponding S Factor shall be established from properly substantiated geotechnical data, with the classes of materials being defined in accordance with the appropriate sections of the Administrative Code of the City of New York.

2. The soil profile considered in determining the S Type shall be the soil on which the structure foundations bear or in which pile caps are embedded and all underlying soil materials.

3. Soil density / consistency referred to in the table should be based on standard penetration test blow counts (N-values) and taken as:
   - (a) for sands, loose - where N is less than 10 blows per foot,
     medium compact - where N is between 10 and 30, and
     compact - where N is greater than 30 blows per foot, and
   - (b) for clays, soft - where N is less than 4 blows per foot
     medium - where N is between 4 and 8,
     stiff to very stiff - where N is between 8 and 30, and
     hard - where N is greater than 30 blows per foot.

4. When determining the type of soil profile for profile descritpions that fall somewhere in between those categories that are provided in the above table, the S Type with the larger S Factor shall be used.

5. For Loose Sands, Silts or Uncontrolled Fills below the ground water table the potential for liquefaction shall be evaluated by the pertinent provisions of the code.

FIGURE 2-6 **Table 3: Comparison of Pertinent Parameters Used for the Static Force Procedure in UBC'88 and the Newly Proposed NYCBC, respectively**

UBC'88 (for NYC)	Proposed NYC BuildingCode
$Z = 0.15$	$Z = 0.15$
So=not defined	$So=2/3$
$S1 = 1.0$	$S1 = 1.0$
$S2 = 1.2$	$S2 = 1.2$
$S3 = 1.5$	$S3 = 1.5$
$S4 = 2.0$	$S4 = 2.5$
$C \le 2.75$	$C \le 2.75$

Table 4: Comparison of Parameters and Formulas Used for the Dynamic Force Procedure in the UBC'88 and the Proposed NYCBC, respectively.

	UBC'88 for NYC (as inferred from Fig 3, p.179 of UBC'88)	Proposed NYC Code
a)	So=not used $S1 = 1.0$ $S2 \approx 1.5$ $S3 \approx 2.3$ S4 undefined $C = 2.5$	$So=2/3$ $S1 = 1.0$ $S2 = 1.2$ $S3 = 1.5$ $S4 = 2.5$ (site-specific study preferred) $C = 2.5$
b)	$S_n = 1 + kT \le C$ for $T \le 0.2s$ k=10 for S1and S2 k= 6.7 for S3	$S_n = 1 + k'T/S_i \le C$ for $T \le 0.2s$ k'=20 for all soil profiles
c)	$S_n = S_i / T \le C$ for $T \ge 0.2s$ Note: use with caution for $T \ge 3s$	$S_n = S_i / T \le C$ for $T \ge 0.2s$ Note: use with caution for $T \ge 3s$
d)	$Z = 0.15$ (Zone 2A for NYC, CT, and northern NJ); $Z = 0.075$ (Zone 1 for southern NJ)	$Z = 0.15$ for NYC

FIGURE 2-7 Table A-2: Soil Types and Site Coefficients (S-Factors)

(Abandoned Version - Not to be adopted for NYCBC, and presented here as an alternate for further evaluation)

Type	Thickness (feet)	Description (for Definition of Material Class see appended Note 1, and for Velocity V* and Blow Count N* see Note 5)	S-Factor
So:		A base of hard rock materials of class 1-65 to 2-65 with shear wave (interval) velocities greater than 7,000 feet per second (fps) overlain by a profile which contains	2/3
	<60	3-65 to 5-65 materials with shear veloc. V*>2000 fps (blow count N*>50); or	
	<30	3-65 to 7-65 materials with V*>1000 fps (N*>20); or	
	<15	3-65 to 11-65 materials with V*>500 fps (N*>10).	
S1:		A base of intermediate to soft rock or hardpan materials of class 3-65 to 5-65 with shear wave velocities greater than 2500 fps or blow counts greater than 80 overlain by a profile which contains	1.0
	<200	3-65 to 7-65 materials with V* > 2000 fps (N*>50); or	
	<100	3-65 to 8-65 materials with V*> 1000 fps (N*>20); or	
	<40	3-65 to 11-65 materials with V*> 500 fps (N*>10); or	
	<100	3-65 to 7-65 materials with V* > 2000 fps (N*>50) and/or less than 25 ft of 6-65 to 11-65 materials with V*> 500 fps (N*>10).	
S2:		A base of hardpan, gravel or sand materials of class 5-65 to 7-65 with shear wave velocities greater than 2,000 fps or blow counts greater than 50 overlain by a profile which contains	1.2
	>200	5-65 to 8-65 materials with V* > 2000 fps (N*>50), or	
	100-200	5-65 to 11-65 materials with V* between 1000 & 2000 fps (N*=20 to 50); or	
	40 - 100	5-65 to 11-65 materials with V* between 500 & 1000 fps (N*= 10 to 20); or	
	<40	7-65 to 11-65 materials with V* between 300 & 500 hps (N*=7 to 10).	
S3		Any profile which contains	1.5
	>200	5-65 to 11-65 with V* between 1000 & 2000 fps (N*=20 to 50); or	
	100-200	5-65 to 11-65 with V* between 500 &1000 fps (N*=10 to 20); or	
	40 - 100	7-65 to 11-65 with V* between 300 & 500 fps (N*=7 to 10); or	
	<40	7-65 to 11-65 with V*<300 fps (N*<7).	
S4:		Any profile which contains	2.5
	>200	5-65 to 11-65 with V* between 500 &1000 fps (N*=10 to 20); or	
	>100	7-65 to 11-65 with V* between 300 & 500 fps (N*=7 to 10); or	
	>40	7-65 to 11-65 with V*<300 fps (N*<7).	

FIGURE 2-7 Table A-2: Soil Types and Site Coefficients (cont'd)

Notes to Table A-2

1. The site S Type and Factor shall be established from properly substantiated geotechnical data, with the classes of materials being identified in accordance with the appropriate sections of the Administrative Code of the City of New York.

2. The soil profile considered in determining the S Type shall be the soil on which the structure foundations bear or in which pile caps are embedded and all underlying soil materials.

3. The S Type with the larger S value shall be used when during determination of the type of soil profile either the soil type itself or the class of material falls somewhere in between those categories that are provided in the above table.

4. For Loose Sands, Silts or Uncontrolled Fills below the ground water table the potential for liquefaction shall be evaluated by the pertinent provisions of the code.

5. The thickness-weighted average blow count, N*, and shear velocity, V*, as used in the above table shall be determined by the following formulae:

(a) $N^* = D / \Sigma (d_i / N_i)$ and $D = \Sigma d_i$,
where each N_i is the directly measured (uncorrected) standard penetration test blow count that is representative for the depth interval, d_i, and where the total thickness, D, is the sum of all the depth intervals d_i.

(b) $V^* = D / \Sigma (d_i / v_i)$ and $D = \Sigma d_i$,
where each v_i is the shear wave velocity that is representative for the depth interval, d_i, and where the total thickness, D, is the sum of all the depth intervals, d_i.

Where both reliable shear wave velocities and standard penetration test blow counts are available, preference should be given to the determination of the soil type "S" based on shear wave velocities rather than blow counts.

Table A-3: Abbreviated Version of the Unified Soils Classes as Used in the New York City Administrative Code (p.194, Table 11-2, Allowable Soil Bearing Pressures) with Classes of Materials Defined as:

Class	Description		Nominal Bearing Pressure (tons / sqft)
1-65	Hard Sound Rock		60
2-65	Medium Hard Rock		40
3-65	Intermediate Rock		20
4-65	Soft Rock		8
5-65	Hardpan		8-12
6-65	Gravel, Gravel Soils		4-10
7-65	Sands [except fine sands]		3-6
8-65	Fine Sands		2-4
9-65	Clays and Clay Soils	Hard	5
		Medium	2
		Soft	needs special analysis
10-65	Silts and Silty Soils	Dense	3
		Medium	1.5
		Loose	needs special analysis
11-65	Nominally Unsatisfactory Bearing Materials (Includes Loose Fill)		needs special analysis

SECTION 3
ADEQUACY OF EXISTING CODE FORMATS

This section addresses changes that might be made keeping the existing format in which a discrete set of standard site conditions - referred to as site categories - are defined, together with soil factors for each category.

Development of site categories is an exercise in balancing simplicity against a rational accounting for the various important aspects of the site effects problem. Many different features of a site, as well as the intensity and nature of the ground motion itself, have a part in the influence of a site upon motion. There is an enormous variety of soils and soil site characteristics across the country. The Workshop concluded that the presently-used arrangement of four site categories, each with a single soil factor, is overly simplistic - and should be overhauled.

The Workshop favored an approach that retained a small number of categories (no more than 5), but with a matrix of soil factors for each category. This matrix would provide for factors such as the impedance contrast between the soil profile and the underlying rock, intensity of ground motion (the non-linearity problem), nature of the ground motion (Influence of possible source effects) and variation of site effect with the spectral ordinate period (frequency) of interest. It was felt that this scheme permits a reasonable and workable balance between over-simplicity and undue complexity.

Development of this approach to the point of possible acceptance and adoption requires two intertwined efforts: (a) choice and description of a set of site categories; and (b) evaluation of appropriate soil factors.

3.1 Site Categories

The Workshop recommends use of five site categories, according to the following general scheme. Short phrases are used here for the sake of brevity; if such a scheme is adopted, longer and more descriptive wording must be given. The designations S0, S1, etc., are used, but the proposed categories do NOT necessarily align with existing categories carrying a similar designation.

S0: Hard rock
S1: Soft rock
S2: Shallow firm soil
S3: Shallow soft soil; deep stiff soil
S4. Deep soft soil

The "hard rock" category is required for eastern parts of the United States as the "datum" for site effects, while the "soft rock" category is similarly needed in California and many other parts of the country as well. The remaining categories are implicitly related to an undefined range of "characteristic" site periods, suitably spaced to cover the entire range of periods appropriate for buildings to which model codes are applicable.[1] Categories S2, S3, and S4 thus encompass several different combinations of stiffness and depth of soil. For example, the S3 category must cover both a shallow stratum of soft clay and a deep deposit of a stiff sand.

This arrangement is not ideal. Theoretically the site amplification is not influenced just by period, but the actual stiffness of the near surface soils is important. However, such a scheme is the best compromise if the number of site categories is to be limited to five.

---

[1] Such periods would NOT be specified in a code, but should be discussed in a commentary. See comments in Section 4 concerning the difficulty of evaluating a site period. The "characteristic" range of site periods associated with each site category would be broad - represented, say, by a factor of 2. The characteristic period ranges of adjacent categories should be envisioned as overlapping, thus helping to give an impression of the imprecision with which both site period and appropriate site category can be determined for a given location.

It was a strong consensus recommendation of the Workshop that the descriptions of the site categories should be more quantitative than at present. That is, use of words "soft", "firm", etc. should be supplanted, to the extent feasible, with numbers related to data from conventional (and where feasible, advanced) methods of site investigation. The level of "quantitativeness" in the proposed seismic provisions for the New York City building code - see Table A.1 in Fig. 2-4 of this report - appears to be about right. The specific numerical soil designations are peculiar to the New York City code, and hence not generally applicable. However, the blow counts in the footnotes to the table do have general applicability. Even better measures of the stiffness of soils, such as shear strength or shear wave velocity, should be presented in the commentary to the code, and be specifically related to the blow counts appearing in the main table.

3.1.1 Soil Factors

It seems likely, or at least possible, that near-term revisions of model codes (led by the 1994 revision of BSSC's NEHRP-Recommended Provisions), will utilize maps for spectral acceleration at two (or possibly even more) periods. Current thinking focuses upon periods of 0.3 and 1.0 seconds. This offers the possibility for having soil factors to be applied separately to these two parameters, and thus beginning to account more realistically (than in current codes) for the way in which site effects change with period. However, an effort to develop a new set of soil factors should also assume that use of only a single ground motion parameter (such as effective peak acceleration) may continue.

Thus the matrix for soil factors for each site category would have two (or possibly three) columns corresponding to different periods on a response spectrum plot. Horizontal rows in the matrix would then give "corrections" for additional factors. A detailed study will be necessary to permit rational choice of appropriate factors and "corrections". This is, in effect, the major study called for in the report from the second Workshop. Section 7 discusses this study further.

3.1.2 Other Comments

The soil factors study will provide information directly applicable to the choice of factors to be applied to response spectral ordinates. There should, eventually, be a second set of factors for use with equations for lateral force coefficients to be used with "static" design procedures. This difference arises because lateral force coefficient procedures presume that structures will experience some yielding and shift of effective fundamental period. Hence, it is not as necessary - in comparison with elastic response spectra for use in design - to envelope different possible periods for site-related spectral peaks.

The Workshop recommends that codes include criteria for identifying sites where soil instability - particularly sites with possible liquefaction - be incorporated into model building codes. It was noted that the building code for Massachusetts contains such provisions, and have functioned effectively. Special studies of such sites should be required before soil factors for use in analysis of a building are provided. Use of a higher soil factor to compensate for possible instabilities may in many situations be improper practice.

A specific question concerned the interpretation of site categories when a building has a basement. Does one evaluate depths and thicknesses starting at ground surface, or at the bottom of the basement? This is related to the question: At what location is base shear applied to the building? The Workshop agreed that the answers to these questions should be consistent. That is, it is appropriate when assigning a site category to evaluate depths and thicknesses counting downward from the basement, and the corresponding base shear should then be applied at the basement. Appendix F reproduces a proposal for the new Greek Seismic Code.

Finally, the Workshop notes that there will inevitably be difficulties in relating language suitable for a nationally-applicable code to every local condition. There are a number of cities and states whose codes already list and define specific designations for soils commonly encountered in the applicable area. The Workshop recommends that such cities and states be encouraged to make local adaptations of the language of a nationally-applicable code.

SECTION 4
DEFINING SITES BY PERIOD INSTEAD OF CATEGORY

Site period has in the past been used in US model codes as a parameter in an equation for calculation of soil factor as a function of period. The calculated soil factor had its largest value when the period of the building coincided with the site period. The use of site period in this way is still favored in other countries (e.g., Chile). The concept was dropped for US model codes for several reasons - difficulty in estimating site period, difficulty in anticipating building period, and abuse by engineers in avoiding penalties given by this site factor.

However, arguments still are heard favoring return to a soil factor expressed as a function of site period. On the one hand, it is pointed out that there often are humps - in the range of 1 sec. to 3 sec. periods - in response spectra observed atop deep, soft ground. Such humps are not modelled by the period independent site factors we use today. In addition, use of site factors calculated from period would avoid having discontinuous changes in site factor along a traverse.

The Workshop cited a number of reasons why it can be difficult to evaluate a site period. These are:

1. In many places, a distinct impedance contrast at the base of the profile is lacking, or the depth to "hard rock" is so great that the concept of a site period is not useful. In the latter case, the amplification in such cases is not sharply peaked as is implied by customary thinking about site periods.

2. If site period were the only variable to be considered, then the code would not distinguish between sites of the same period underlain in one case by firm alluvium or in the other by soft clays over alluvium.

3. Some concern was expressed as to whether the site period would be adequately determined in practice for a routine project.

The Workshop agreed that for a particular site condition, the site period is probably unknown over at least a factor of two. In addition, for some sites, under high strain, the period will lengthen considerably. Given that the period of a building also lengthens with corresponding uncertainty, it seems impractical to characterize a site period by a single number, implying an accuracy and utility which does not exist.

For these reasons, the Workshop recommends against use of site period as a parameter in an equation for soil factor.[2]

However, the Workshop did recognize that site period has an important indirect role (as previously discussed) in helping to choose and define site categories. There was much broader agreement for using site period, in a generalized sense or as a concept, in defining site categories or in arriving at appropriate site factors. If a site is to be characterized by period, it should be done over a rather wide range, which is what site category definitions should be expected to do. In defining site categories, some care should be exercised to provide for a broad range of site periods. A commentary should indicate the range of periods associated with each site category.

---

[2] One member of the Workshop pointed out that there are other ways of obtaining gradations than use of site period, e.g., average shear velocity down to a specified depth.

SECTION 5
TOPOGRAPHIC AND BASIN EDGE CONSIDERATIONS

This section deals with the effect of topographic features, such as ridges and slopes, upon earthquake ground motion. Also in this same category is the effect of non-horizontal subsurface features, particularly the complex phenomena that can occur where buried rock slopes upward sharply at the edges of basins. There is considerable evidence from the field of the importance of both effects. Most such evidence is inferential and based upon distribution of damage to buildings. In addition, there is as well now a growing body of ground motion recording. In addition, the literature contains many theoretical studies predicting the influence of both above-ground and subsurface topographic features. However, relatively little work has been done to reduce this mass of information to a form that provides useful guidance to engineers.

Both field observations and analyzed studies have shown that rock ridges can amplify peak accelerations (for example, the Pacoima Dam record in the San Fernando earthquake), particularly at high frequencies - above 3 to 5 Hz. Simple theoretical 2-D models have demonstrated that their effect depends on many factors including slope angle, wave type, angle of wave incidence, characteristic dimension of topographic feature, location of site on topographic feature, and wave frequency. The French code has incorporated a coefficient in its base shear formula that considers topography in a simple manner (see Appendix E).

There is also compelling evidence concerning amplification of ground motions near basin edges (for example, the Caracas earthquake of 1967). Now the effects are upon longer period components of ground motion - say 1 Hz or less and are substantially greater than ridge effects. Here the phenomena are particularly complex, and as yet there are no known efforts to produce code-like provisions for this topographic effect.

Although the participants agreed that topography was potentially significant, they generally believed that the effect was difficult to reliably quantify and that the introduction of topographic factors into U.S. codes in the near future is premature. Hard data from ground motion recordings is not yet adequate (to the same degree as the data for site effects for more-or-less level ground) to justify development of general rules. A possible exception is the situation of sharp ridges. The Workshop does recommend that the topographic factor in the French code, along with supporting documentation, be collected and studied and that the possible inclusion of this particular topographic effect be considered in seismology code committees. Perhaps critical topographic features could be defined (in terms of slope angle and height), which would lend to nominal increases, in the high frequency spectral ordinates, of say 30% (if topographical feature exceeds a critical parameter).

SECTION 6
PRESCRIPTIONS FOR USE OF TIME HISTORY INPUTS

Dynamic analysis of buildings is required by model codes for some situations (such as very irregular framing systems in Zone 4), and recommended for analysis of buildings in still other situations. Such analyses are almost always performed using response spectrum techniques, and are basically linear analyses. Analyses using a time-history of ground motion as input are used only in exceptional circumstances - involving critical facilities, etc.

However, linear dynamic analyses based upon response spectrum input cannot capture the true behavior of structures being strained into the non-linear range. One very important feature that is omitted is the influence of number of cycles of inelastic straining, which is related to the duration of ground motion. Various approximate methods for accounting for the duration have been suggested. However, the first Workshop concluded that actual non-linear behavior can be captured only through dynamic analyses using a time-history of ground motion (i.e. an accelerogram) as input. While much additional research and development is needed to evolve suitable and reliable methods for performing such analyses on a regular basis, the first Workshop predicted that by the year 2000, the use of analyses with time-history inputs will be much more widespread. Not everyone at the present Workshop agreed with this conclusion. However, it was used as the basis for discussion of possible guidelines concerning the effect of site conditions upon selection of time-history inputs.

Before going into specific approaches to select/generate these time-histories, several points of consensus are clear. First, the time-histories should reflect realistically the ranges of magnitudes, source types, distances, and site conditions of interest. Second, several time-histories should be used for each building (at least 3 or 4). Third, both earthquake engineers and seismologists should be involved in the process, whatever approach is taken.

The Workshop agreed that the first step is to define, either at ground surface or at depth, the characteristics of the response spectrum appropriate for the site. Duration of strong ground shaking, and other possible key features - e.g., the pulse characteristic of near-source ground motion - must be established. Then there are several acceptable methods for selecting and developing appropriate time-histories. They include: (a) synthetically modifying recorded ground surface motions to " match" the target spectrum; (b) selecting a suite of recorded ground surface motions that, in the aggregate, "match" the target spectrum in the range of periods of interest; and (c) propagating either rock motions - or synthetically-modified rock motions - that "match" a target rock spectrum - through the soil column. When time-histories are defined at rock and propagated through a soil column, additional evaluation should be made of the motions computed at ground surface, to ensure that they have realistic characteristics. Guidelines should be developed for conduct of such analyses.

All of these approaches are applicable to a specific site. If motions are being generated as input to only one structure at the site, then it suffices to "match" the target spectrum only over the range of periods appropriate for that building - with due allowance for uncertainties in site and building periods, and for period lengthening due to non-linear response of the building. If motions are to be useful as input to a range of structures, then the target spectrum must be matched over a wide range of periods. If time-histories suitable for an area (e.g., a city) are sought, then it will be necessary to follow the third approach and choose motions appropriate for rock.

The growing collection of strong ground motion records should be assembled into readily accessible, centralized catalogs - up-to-date and appropriately documented. Simple-minded scaling should be discouraged, and clear guidelines for this and other modifications of available records should be available. If strong motions representative of site specific conditions under study are available, then their use should be strongly encouraged.

SECTION 7
LOOKING AHEAD

The Structural Engineers Association of California (SEAOC) has recently made plans for a major effort to update, revise and expand its publication ("the Blue Book") concerning seismic design. These plans now call for a series of such publications covering various aspects of the problem. The issues discussed in this Workshop are part of the SEAOC agenda. Several committees have been formed, and detailed outlines for these publications are now being formulated, with the format to be finalized in December of this year. A workshop is scheduled for April 1992. The first draft is due for completion in June or July 1992, with final draft in June 1993.

The Building Seismic Safety Council (BSSC) is now beginning a cycle of effort leading up to the 1994 revision of the NEHRP Recommended Provisions - with the initial expectation of suggesting major changes in the way in which lateral forces are to be determined. Detailed plans for the effort will be formulated by early 1992. Proposals for changes must be completed by March 1993.

Thus there are opportunities to work for implementation of recommendations developed by this Workshop, but the time schedule for formulating specific proposals and doing the necessary additional studies is short.

7.1 Requirements for Renewed Major Study of Site Effects

As discussed, in Section 3, there is need for a major study to develop specific recommendations concerning soil factors. This study must investigate the influence of a number of important parameters, so as to determine whether or not they have a significant influence upon site effects, and if so to quantify factors for taking these parameters into account in code-based design calculations.

A very considerable number of ground motion recordings have been made since the last systematic study - by H.B. Seed and his colleagues and students, in the early 1970's (see Seed and Idriss, 1982) - of the effect of site conditions upon such recordings. All available recordings together with associated local geology descriptions, should first be assembled into a common data base. These accelerograms should be grouped according to magnitude and distance. Several trial site categories should be selected, and accelerograms grouped accordingly. A first step is to compute response spectra from the accelerograms, and "eyeball" the collection for any evident trends. A number of different approaches can then be applied to analysis of these data.

1. Simple statistical averaging (a la Seed et al, 1976): Try several different schemes for normalizing these spectra: by peak ground acceleration, by peak ground velocity, etc. The normalized spectra should then be examined for trends with regard to intensity of shaking and site conditions, for different magnitude and distance ranges. 50th and 84th percentile spectral shapes should be computed for each category.

2. Quantification and/or regression analyses: Perform regression analysis for spectral ordinates at several different periods, as a function of site conditions, magnitude and distance. The selected site conditions should be used for this purpose.

3. Simple Comparative Studies: Compare response spectra for specific site pairs (S1 vs. S2, S3 vs. S4, etc.) using recordings from adjacent sites during the same earthquake.

Depending upon the outcome, the definitions of site conditions should be revised and other iterations of foregoing analyses performed until acceptable site definitions and site dependent spectra are obtained.

Because of the incompleteness of data for soil effects from recordings during actual earthquakes, it will also be necessary to make extensive use of theoretical calculations for study of the various effects. Use of the SHAKE program is recommended for this purpose. However, it will be essential - early in the study - to calibrate findings with actual ground motion recording data. Hence it is recommended that the study begin using sources typical of the western US; that is, use ground motion recordings made on rock in California or other similar seismic environments.

7.1 Current and Anticipated Studies

Several efforts to compile and analyze the data base of ground motion recordings are underway.

* At the new Southern California Earthquake Center, headquartered at the State University of Southern California, plans have been made to process and compile an extensive set of recordings available within files of the University. This compilation effort will require several years.

* At Menlo Park, the USGS is starting to redo regression analyses using a larger data base. However, at this point, plans have not been made for incorporating the role of site conditions. If possible, the study should be expanded to place focus on site effects, to see how computed regression curves relate to current standard site conditions.

* At the University of California at Davis, effort has been focused upon checking the validity of the SHAKE computer code for predicting amplification effects for pairs of sites where recordings are available. The influence of non-linearity is of special interest. Model tests will be performed using centrifuge techniques, to supplement data from the field. This is being followed by examination of data from pairs of sites to look for trends

concerning intensity of shaking, nature of sites, etc.; that is, all data from some 200 sites will be "eyeballed".

* At the University of California at Berkeley, analysis of pairs of records are underway. Results are being applied to develop site effects rules for use by CalTrans.
There are other studies as well, by private consultants (e.g. Geomatrix) and through EPRI, which will at some point become available through papers or reports.

A theoretical study of appropriate values for soil factors is currently beginning through NCEER (in the persons of Martin, Dobry, Papageorgiou and others). This will be a parametric study, examining the influence of what are thought to be the most important factors. This Workshop recommends that the study proceed in the following manner. A set of factors, ways of characterizing these factors, and significant "values" for these factors, must be established. The following scheme is suggested:

1. Source effects: characterized as Western US, Central/Eastern US, and subduction zone.

2. Intensity of ground shaking: Initially, the best characterization for intensity appears to be the spectral acceleration for an S0 (or S1) site, at a characteristic (low) period for that site. Three levels of intensity should be considered, corresponding roughly to a level below the expected threshold of significant non-linearity for sites with soft soils, about at that threshold, and above the threshold. Possibly it will be found that soil factors applicable at and above the threshold are much the same, and if so, the number of different factors required in a code can be reduced.

3. Impedance contrast: Several ways for characterizing the impedance ratio should be considered. One would involve the ratio of the impedance of underlying rock to the impedance of the softest near-surface soil. Another

scheme should use the weighted average of the impedance of the entire soil column.

7.2 Facilitating Committee and Future Workshop

In order that on-going and planned studies be coordinated effectively, and to ensure that maximum use is made of results in the upcoming code-updated efforts of SEAOC and BSSC, the Workshop recommended that a Coordinating Committee be formed. The Organizer was asked to designate members for such a Committee, and as a result the following attendees were assigned: Crouse, Dobry, Idriss, Joyner, Martin and Power, with Power designated to convene the first meeting.

The group met at the end of the Workshop and planned its future activities, which include subsequent meetings, a workshop to be held in about a year, and fundraising efforts to support the meetings and the workshop.

SECTION 8
SUMMARY AND CONCLUSIONS

The Workshop concluded that major revisions are needed in the present scheme for categorizing sites in the seismic provisions of model building codes. While continuing to favor discrete categories (rather than using site period), there is need for:

- More quantitative descriptions of the several categories, in terms of measure of stiffness of the soils and depths of strata.
- Additional categories explicitly recognizing different stiffnesses of rock.
- Soil factors that take into account intensity of shaking, impedance contrast between the soil column and underlying rock, and possibly earthquake source characteristics.

On-going and future research efforts involving analyses of available ground motion recordings and theoretical studies should be aimed at establishing the basis for such improvements.

In order that these research efforts can have an impact upon the next cycle of revisions to model codes, there must be good coordination among all researchers. A committee to facilitate this cooperation has formed out of the Workshop's participants.

SECTION 9
REFERENCES

Applied Technology Council, Tentative Provisions for the Development of Seismic Regulations for Buildings, ATC Pub. ATC- 3-06, NBS Special Pub. 510, and NSF Pub. 78-8, (June 1978).

Federal Emergency Management Agency, NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings, Part II, Commentary, prepared by the Building Seismic Safety Council, FEMA 96, Washington, DC (1988).

French Association for Earthquake Engineering, Recommendations AFPS 90 for the Redaction of Rules Relative to the Structures and Installations Built in Regions Prone to Earthquakes, Saint-Remy-les-Chevreuse, France (1990).

Jacob, K.H., Seismic Hazards and the Effect of Soils on Ground Motions in the Greater NY-City Metropolitan region, Geotechnical Aspects of Seismic Design, Foundation and Soil Mechanics Group, Metropolitan Section, ASCE, NYC, NY (November 13-14, 1990), pp. 1-24.

International Conference of Building Officials, Uniform Building Code (UBC, 1988), Whittier, California.

Seed, H.B. and I.M. Idriss, Ground Motions and Soil Liquefaction During Earthquakes, EERI Monograph Series, Berkeley, CA (1982).

Taylor, Jonathan, An Evaluation of Site Factors in Building Codes, MS Thesis, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, MA (1992).

Whitman, R.V. ed., Workshop on Ground Motion Parameters for Seismic Hazard Mapping, Technical Report NCEER-89-0038, National Center for Earthquake Engineering Research, State University of New York at Buffalo, Buffalo, NY (July 17-18, 1989).

Whitman, R.V. ed., Second Workshop on Ground Motion Parameters for Seismic Hazard Mapping, National Center for Earthquake Engineering Research, State University of New York at Buffalo, Buffalo, New York (April 11-12, 1990), in preparation.

APPENDIX A
LIST OF PARTICIPANTS

NCEER Workshop on Seismic Hazard Mapping

October 24-25, 1991

Dr. Ian G. Buckle
Deputy Director
National Center for Earthquake
Engineering Research (NCEER)
105 Red Jacket Quadrangle
State University of New York at Buffalo
Buffalo, NY 14261
Phone: 716-636-3391
FAX: 716-636-3399

Dr. C.B. Crouse
Associate
Dames & Moore
500 Market Place Tower
2025 First Avenues
Seattle, WA 98121
Phone: 206-728-0744
FAX: 206-448-7994

Dr. Neville C. Donovan
Principal Engineer/Partner
Dames & Moore
221 Main Street
Suite 600
San Francisco, CA 94105
Phone: 415-896-5858
FAX: 415-882-9261

Dr. Ricardo Dobry
Professor
Department of Civil Engineering
Rensselaer Polytechnic Institute
Troy, NY 12180-3590
Phone: 518-276-6934
FAX: 518-276-8788

Dr. George Gazetas
Professor
Civil Engineering
137 Ketter Hall
State University of New York at Buffalo
Buffalo, NY 14260
Phone: 716-636-3634
FAX: 716-636-3733

Dr. W. Paul Grant
Senior Associate
Shannon & Wilson, Inc.
400 N.34th St.
Suite 100
Seattle, WA 98103
Phone: 206-632-8020
FAX: 206-633-6777

Dr. Howard H-M. Hwang
Professor
Center for Earthquake Research
and Information
Memphis State University
3890 Central Avenue
Memphis, TN 38152
Phone: 901-678-4830
FAX: 901-323-2857

Dr. Mary Ellen Hynes
USAE Waterways Experiment Station
CEWES-GG-H (Dr. Hynes)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Phone: 601-636-3111
FAX: 601-634-3453

Dr. I.M. Idriss
2097 Bainer Hall
Department of Civil Engineering
University of California
Davis, California 95616
Phone: 916-752-5403
FAX: 916-752-7872

Mr. O. Allen Israelson
Building Seismic Safety Council
4th Floor
1201 L. Street, NW
Washington, DC 20005
Phone: 202-289-7800
FAX: 202-289-1092

Dr. William Joyner
Office of Earthquakes, Volcanoes
& Engineering
US Geological Survey
245 Middlefield Road
MS 977
Menlo Park, CA 94025
Phone: 415-329-5619
FAX: 415-329-5163

Dr. Geoffrey R. Martin
Research Professor
Department of Civil Engineering
University of Southern California
KAP224B, University Park
Los Angeles, Ca 90089-2531
Phone: 213-740-9124
FAX: 213-744-1426

Dr. Apostolos S. Papageorgiou
Assistant Professor
Civil Engineering
Rensselaer Polytechnic Institute
Troy, NY 12180-3590
Phone: 518-276-6331
FAX: 518-276-4833

Dr. David M. Perkins
US Geological Survey
OSM, Room 446
Mail Stop 966
Denver, CO 80225
Phone: 303-236-1616
FAX: 303-236-0618

Dr. Maurice Power
Geomatrix Consultants, Inc.
One Market Plaza
Spear Street Tower, Suite 717
San Francisco, CA 94105
Phone: 415-957-9557
FAX: 415-434-1365

Dr. Kyle M. Rollins
Assistant Professor
Civil Engineering Department
368 Clyde
Brigham Young University
Provo, UT 84602
Phone: 801-378-6334
FAX: 801-378-2478

Mr. Leonardo Seeber
Associate Research Scientist
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, NY 10964
Phone: 914-359-2900
FAX: 914-359-5215

Dr. J.P. Singh, President
Geospectra
Suite 213
3095 Atlas Road
Richmond, CA 94806
Phone: 501-222-5700
FAX: 501-222-5988

Dr. Cetin Soydemir
Vice President
Haley & Aldrich, Inc.
58 Charles Street
Cambridge, MA 02141
Phone: 617-494-1606
FAX: 617-577-8142

Mr. David Sykora
USAE Waterways Experiment Station
Attention: CEWES-GG-H
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Phone: 601-634-3551
FAX: 601-634-3453

Mr. Jonathan Taylor
Department of Civil Engineering
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139
Phone: 617-253-7127
FAX: 617-253-6044

Dr. Robert V. Whitman
Professor
Department of Civil Engineering
Room 1-342
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

Phone: 617-253-7127
FAX: 617-253-6044

APPENDIX B
PRELIMINARY AGENDA

Thursday 24 October

7:30-8:15 AM	Shuttle from Marriott to UB Ketter Hall
8:00 AM	Continental Breakfast - Room 140
8:30 AM	Opening remarks by Organizer: objectives, format (Whitman)
8:40 AM	SEAOC's new committee and its plans (Singh)
8:50 AM	Next revision cycle for BSSC (Israelson and others)
9:00 AM	Presentation and explanation of results from questionnaire, plus results from SHAKE analyses (Whitman, Taylor)
9:30 AM	Split into two discussion groups. Quiet time for perusing background material. Discussion of question: Are there corrections/improvements that should be made within present code format? More categories, different S-factors, more quantitative description of site categories, etc.? Specific advice regarding additional research, if needed. Rooms 140 and 236

Coffee available from 10:00 AM

11:30 AM	Reconvene entire Workshop to discuss preliminary conclusions of groups regarding above questions. Room 140
12:00 NOON	Informal Buffet Lunch - outside Room 140
12:45 PM	Entire Workshop: Organizer's latest marching orders
1:00 PM	Reconvene two discussion groups for continued discussion and formulation of recommendations.

Refreshments available from 2:00 PM

2:30 PM	Reconvene entire Workshop to discuss conclusions of groups regarding above questions. Agree on at least preliminary conclusions.
3:30 PM	Split into two (probably different) discussion groups. Discussion of questions: (a) Should there be an entirely different code format (use of site periods?) in the near future?, and (b) How should site effects be considered (in building code context, remember) if time-histories are to be selected as input to dynamic analysis (a longer range question)?
4:30 PM	Tours of Seismic Simulator Laboratory - Room 103 Ketter Hall and Information Service - Room 304 Capen Hall
4:30-5:45 PM	Buses return to hotel
7:00 PM	Informal Cash Bar at Marriott

7:30 PM	Dinner - Salon A
8:30 PM	Informal presentation concerning NCEER's organization and plans for second half-decade (Buckle).

Friday 25 October

7:30-8:15 AM	Shuttle from Marriott to UB Ketter Hall - Room 140
8:00 AM	Continental Breakfast
8:30 AM	Latest marching orders from Organizer
8:45 AM	Back to discussion groups, with updated assignments. One additional question: Should, and if so how, topographic site features be included in building codes?

Coffee available from 10:00 AM

10:30 AM	Reconvene Workshop as a whole. Discussion, conclusions.
12:00 NOON	Informal Buffet Lunch - outside Room 140
12:45 PM	Entire Workshop; Organizer's latest marching orders.
1:00 PM	Entire Workshop, or special working groups as needed: Finalize conclusions and recommendations.
2:30 PM	Concluding session.
3:00 PM	Adjournment Transportation to Airport/Hotel as needed.

APPENDIX C
SUMMARY OF RESPONSES TO PRE-WORKSHOP QUESTIONNAIRES

The Third NCEER Workshop on mapping of seismic shaking hazard for building code purposes, will investigate the adequacy for the workshop, a questionnaire was sent to 35 researchers and professionals in the seismic engineering field during July and August of 1991.

The purpose of the questionnaire was to collect information on the use of current site categories, to investigate the kinds of problems experienced, and to obtain suggestions for improvement. A copy of the questionnaire is included in Appendix 1.

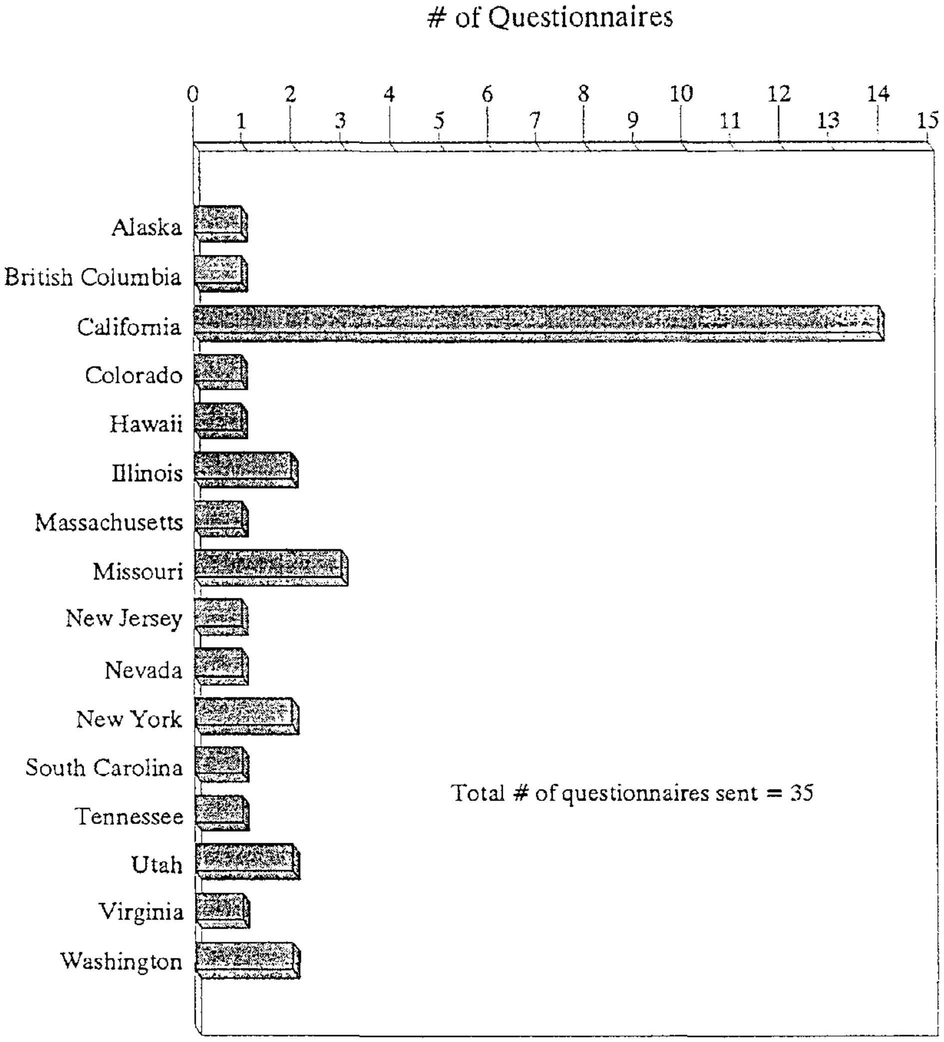
Responses were received for 9 different metropolitan areas or regions: Anchorage, AK; Vancouver, BC; San Francisco, CA; New England; St. Louis, MO; Portland, OR; Memphis, TN; Salt Lake City, UT; and Seattle WA. Fourteen people replied and one person provided details for three different metropolitan areas, thus making a total of 16 responses. A summary of results, presented in factual format in graphs and tables in included in Appendix 2.

In addition to the questionnaire, information on typical soil profiles for use in site response analysis was provided, together with references to professional papers concerning analysis of site responses.

Many thanks to those who responded.

SITE CATEGORIES QUESTIONNAIRE

Geographical Distribution of Questionnaires Sent



SITE CATEGORIES QUESTIONNAIRE

From______________________
Organization__________________
Metropolitan Area______________

If you have experience in more than one metropolitan area, please xerox this sheet and complete these tables for each area.

1. TYPICAL SITE CONDITIONS -I

Within the metropolitan area where you have the most experience, how often are sites encountered that fall into?:

	Never	Very Seldom	Fairly Often	Often	Always
S1	_____	_____	_____	_____	_____
S2	_____	_____	_____	_____	_____
S3	_____	_____	_____	_____	_____
S4	_____	_____	_____	_____	_____

Please check the appropriate box on each line.

How often do you encounter serious difficulties in deciding which site category to assign to a site?:

Never	Very Seldom	Fairly Often	Often	Always
_____	_____	_____	_____	_____

Please describe the types of sites that give difficulties.

2. What peak ground acceleration is now typically assumed for design of projects in your area? Does this acceleration apply atop rock (how hard?) or atop soil (what category of soil?)

3. How common is it to perform site-specific response analyses in your area?:

Never	Very Seldom	Fairly Often	Often	Always
_____	_____	_____	_____	_____

4. Can you suggest better definitions for standard site categories?

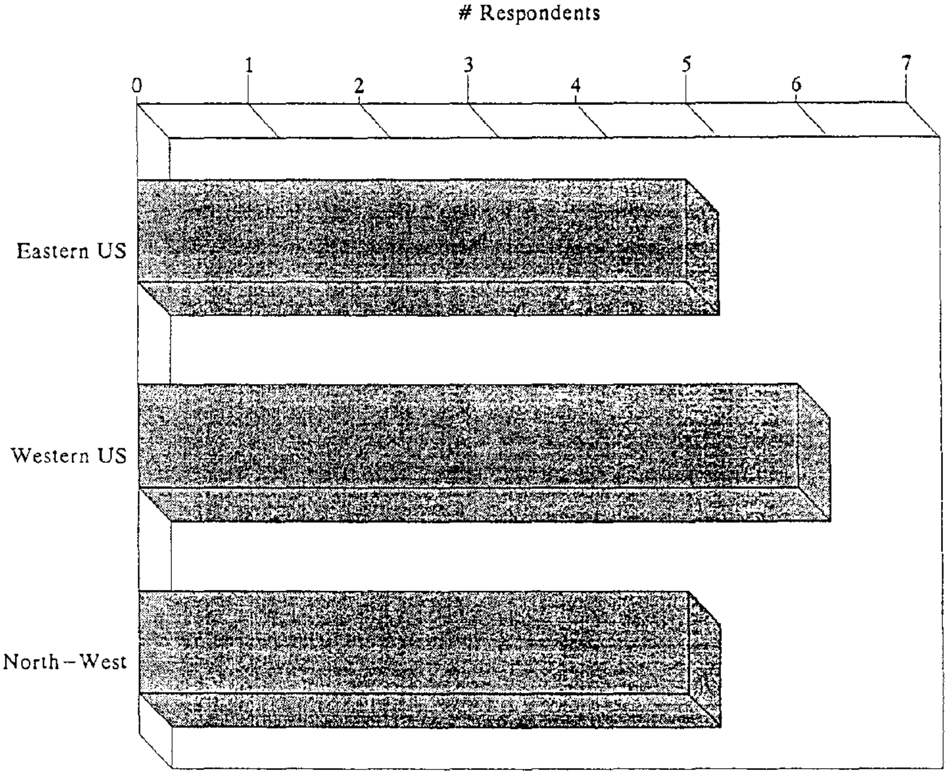
5. Do you feel that the relative soil factors assigned to the current categories are reasonable? If not, what would you suggest?

2. TYPICAL SITE CONDITIONS -I I

Could you please supply a set of soil profiles typical of those encountered in your practice? Copies of boring logs or profiles from reports or papers will suffice. Naturally we are interested in quantitative descriptions of the stiffness of the soils - blow counts, shear wave velocities, etc. - and also data for unit weight, PI, etc., if they are readily available. If you prefer, you may indicate typical profile conditions using the following sheet.

RESULTS OF SITE CATEGORIES QUESTIONNAIRE

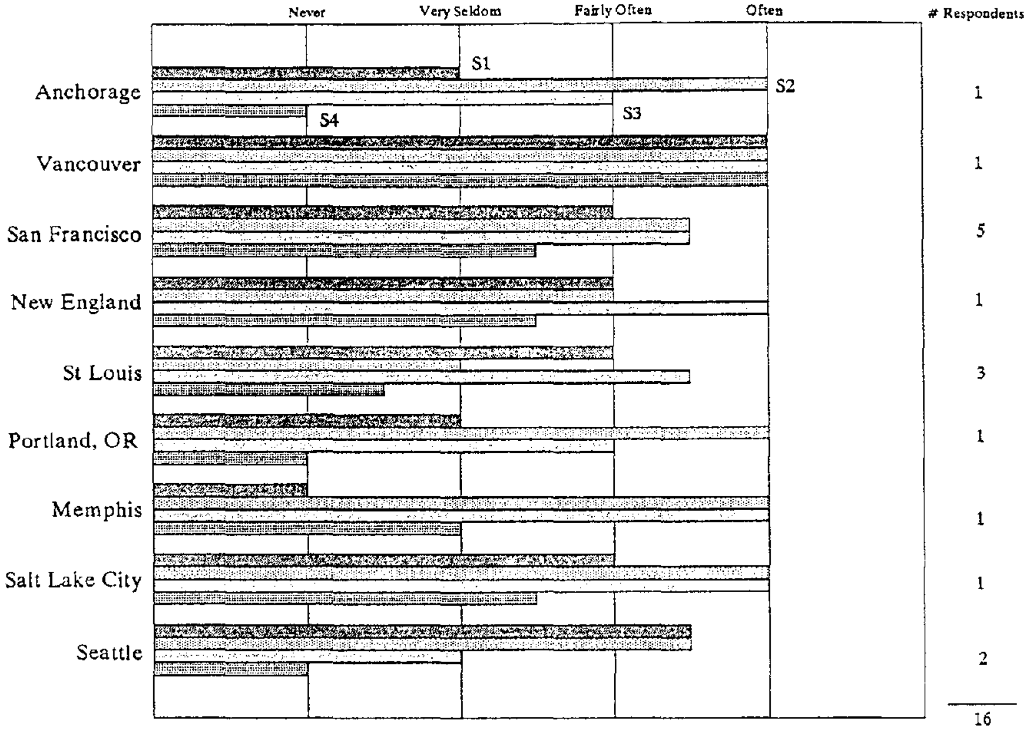
Geographical Distribution of Responses

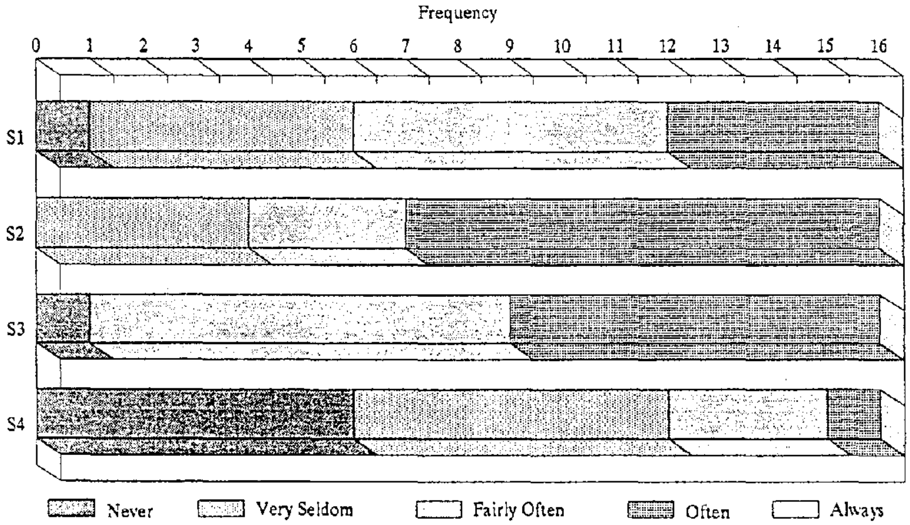


Total # Respondents = 16

RESULTS OF SITE CATEGORIES QUESTIONNAIRE

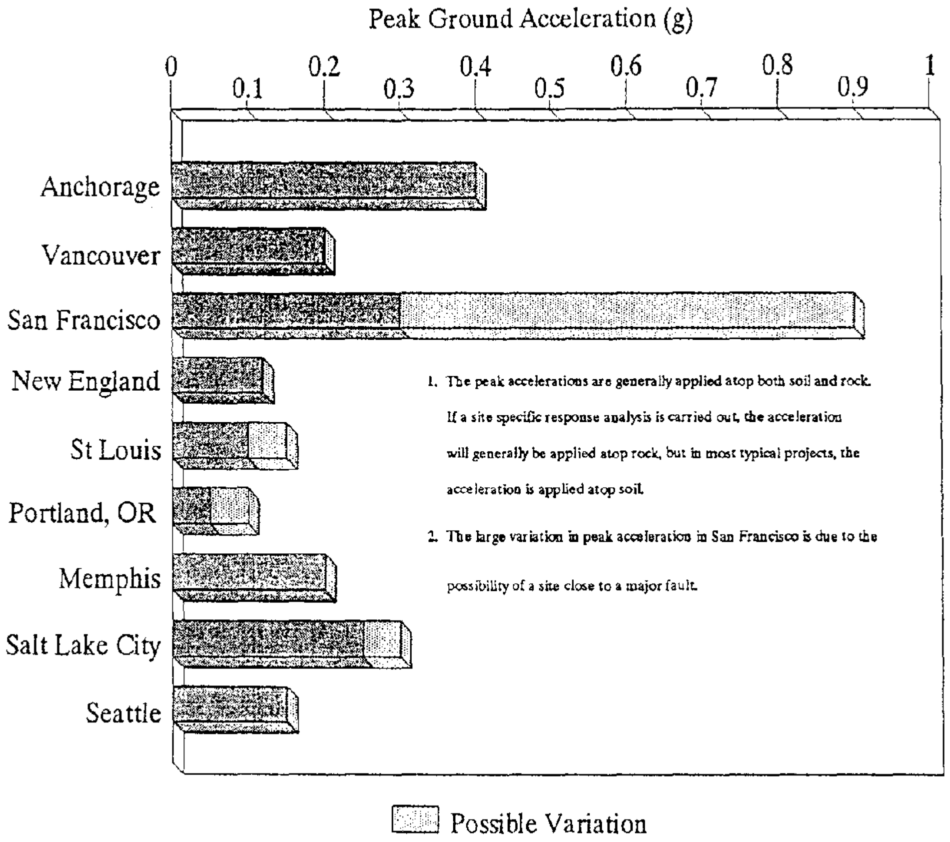
Q. How Often Do Sites Fall into the Current Code Categories ?





RESULTS OF SITE CATEGORIES QUESTIONNAIRE

Q. What Peak Acceleration is Typically Used in Design Projects ?



1. The peak accelerations are generally applied atop both soil and rock. If a site specific response analysis is carried out, the acceleration will generally be applied atop rock, but in most typical projects, the acceleration is applied atop soil.
2. The large variation in peak acceleration in San Francisco is due to the possibility of a site close to a major fault.

Q. How Common Is It to Perform Site Specific Response Analyses in Your Area?

- In general, site specific reponses are very rarely carried out.

- In the Western US and Northwest, particularly since the Loma Prieta Earthquake, it is becoming fairly common to carry out site specific response analyses for high rise buildings, highway bridges and other major public works projects

- Liquefaction studies are carried out fairly often, particularly in San Francisco

RESULTS OF SITE CATEGORIES QUESTIONNAIRE

List of People Who Responded to the Questionnaire

Name	Organization	Area	State
W. Paul Grant	Shannon and Wilson Inc.	Anchorage	AK
W.D. Liam Finn	University of British Columbia	Vancouver	BC
Roger D. Borcherdt	U.S. Geological Survey	San Francisco	CA
Neville C. Donovan	Dames and Moore	San Francisco	CA
Maurice S. Power	Geomatrix Consultants	San Francisco	CA
Robert Pyke	Consulting Engineer	San Francisco	CA
Raymond B. Seed	University of California at Berkeley	San Francisco	CA
Cetin Soydemir	Haley and Aldrich, Inc.	New England	MA
Duane Atchley	Sverdrup Corporation	St. Louis	MO
Tom Cooling	Woodward Clyde Consultants	St. Louis	MO
Stephen L. McCaskie	Sverdrup Corporation	St. Louis	MO
W. Paul Grant	Shannon and Wilson, Inc.	Portland	OR
Howard H.M. Hwang	Memphis State University	Memphis	TN
Kyle M. Rollins	Brigham Young University	Salt Lake City	UT
C.B. Crouse	Dames and Moore	Seattle	WA
W. Paul Grant	Shannon and Wilson, Inc.	Seattle	WA

APPENDIX D
SUMMARY OF PRE-WORKSHOP SHAKE ANALYSES

List of Soil Profiles Analyzed:

Metropolitan Area	Site Category
Boston #1	S1
Boston #2	S1
Memphis #1	S2
Memphis #2	S2
St. Louis #1	S1
San Francisco #1	S4
San Francisco #2	S2
San Francisco #3	S3/S4
Seattle #1	S2

APPENDIX E
PROPOSED FRENCH CODE PROVISIONS FOR TOPOGRAPHIC EFFECTS

The following figures and text come from the French Association for Earthquake Engineering[3] for a topographic site factor. The first figure plots the factor τ' vs. the slope i. Subsequent figures show the application of this factor to various situations.

---

[3] The material shown on pages E-2 through E-5 is used by permission from the French Association for Earthquake Engineering.

C.5.33.

Both theory and experiment show that certain particularities of the surface or underground topography are liable to induce amplifications of the seismic motion in certain frequency ranges. These amplifications may locally reach sizeable values. In the present state of knowledge, it is not possible to establish general rules giving more than a very poor approximation of the place and magnitude that can be foreseen for these amplifications.

Empirical coefficients given in the article on the opposite page should be considered as design coefficients intended on reducing the mean risk and on deterring from choosing settlements of which it has been proven by experience that they might be liable to be dangerous. The whole article 5.33 should be considered as provisional.

C.5.331.2.

In order to estimate τ, relief elements that should be taken into account are those that affect the general site configuration, as shown for example by topographical surveys and vertical sections used for the general site investigations, at the scale and with the density of points of measurement generally admitted for this type of investigation. Purely local relief accidents shall be considered as having no effect on the seismic motion.

It is reminded that lines of largest slope and contour lines are orthogonal (property retained in horizontal projections). Therefore, if P is on a more or less horizontal shelf, it shall be considered that lines of largest slope coming from or going to P are defined by the lines originating in P and normal to the contour line(s) delimiting the shelf (Figure 5.331.2a).

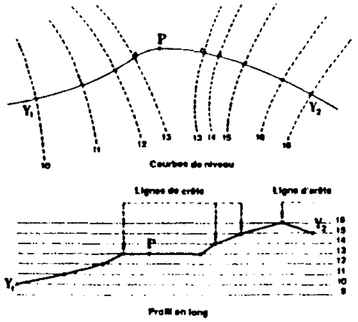


Figure 5.331.2a

5.33. SITE RESPONSE FACTOR

5.331. GENERALITIES AND DEFINITIONS

5.331.1.

Except if the effect of the topography on the seismic motion is directly taken into account using a dynamic calculation based on a proper idealization of the relief, a multiplying coefficient τ called site response factor or topography factor will be used.

5.331.2.

The coefficient τ relative to a given point P of the site will be conventionally determined from certain characteristics of the longitudinal section of the steepest gradient line going to P (Figure 5.331.2a).

In the particular cases when it is possible to define several steepest gradient lines going to P (spurs, peaks), the association of partial sections most unfavourable for point P will be considered (Figure 5.331.2.b).

Section drawings will represent great mass excavations if the latter are large enough to justify this or make it necessary.

C.5.331.2. (Continued)

Situations at the foot of a cirque or on a spur or peak are represented in the following drawings :

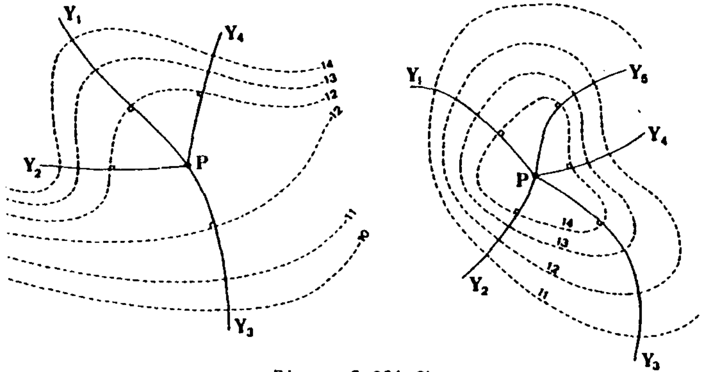


Figure 5.331.2b

The section to consider is the most unfavourable of composite sections Y_i P Y_j.

C.5.331.3.

A ridge line or watershed line means a line of changing slope corresponding to a convexity of the relief, both slopes going in the same direction (or one of them being horizontal) in the first case, in opposite directions in the second case.

5.331.3.

When the section has been schematically broken up into successive parts within which the slope may be considered as uniform, relative to the scale of the relief, relief elements that play a role in calculating τ are :

- ridge ledges close to point P, under certain conditions (article 5.332);
- the possible closeness of watershed ledges (article 5.333) or of spurs and peaks (article 5.334).

5.331.4.

The value of τ to retain in order to determine the design seismic motion to apply to a construction will be the most unfavourable value obtained on the bearing surface of the construction.

C.5.332.1.

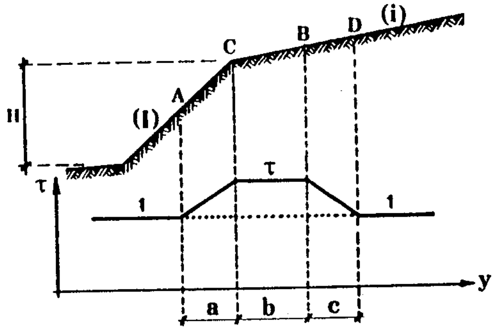
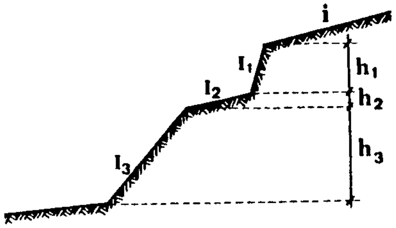


Figure 5.332.1a

The determination of H leaves a large latitude to self-judgment. As an example, one may consider as base of the relief the point above which the general slope of the site becomes inferior to 0.4 again.

The determination of I may also set a few problems if the segment of slope I is of small length. In a situation like the one of figure 5.332.1b, II may be replaced by the weighted average :



$$I_m = \frac{\sum h_i I_i}{\sum h_i}$$

Figure 5.332.1b

These remarks also apply to further articles.

5.332. RIDGE LEDGES

5.332.1.

If one considers a ridge C delimiting a downhill slope of gradient I (tangent of the slope angle) and an uphill slope of gradient i, and if :

- $H \geq 10$ m (H being the height of the ridge above the base of the relief)
- $i \leq I/3$

Coefficient τ :

- takes the value :

$\tau = 1$ for $I-i \leq 0.40$
$\tau = 1 + 0.8\ (I-i-0.4)$ for $0.40 \leq I-i \leq 0.90$
$\tau = 1.40$ for $I-i \geq 0.90$

On segment CB of the uphill slope defined by length b of its horizontal projection (expressed in meters) :

$$b = \text{minimum of} \left\{ \begin{array}{l} 20\ I \\ \dfrac{H + 10}{4} \end{array} \right.$$

- is given by a linear relation connecting the values 1 and τ along segments AC and BD, of length :

$$\left\{ \begin{array}{l} a = AC = H/3 \\ c = bd = H/4 \end{array} \right.$$

- takes value 1 downhill from point A and uphill from point D.

C.5.332.2

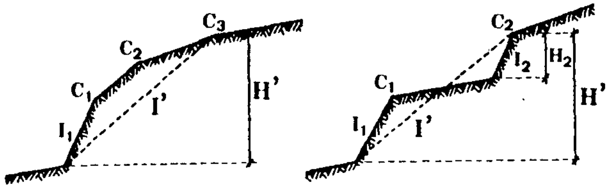


Figure 5.332.2

C.5.333

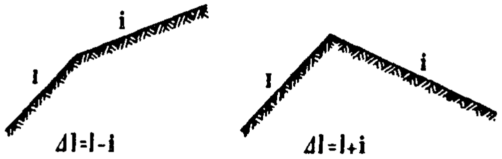


Figure 5.333

C.5.334

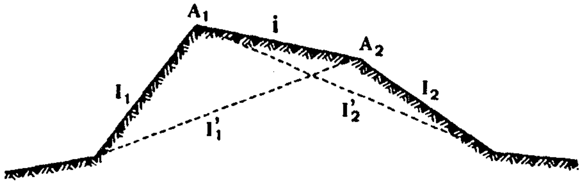


Figure 5.334

5.332.2.

In the case of several successive ridge lines C1, C2..., one will consider, beside individual effects of these ridges or changes of slope, the fictitious ridges of slope I' defined in figure 5.332.2.

5.333. WATERSHED LEDGES

The situation of watershed ledges (slopes I and i in opposite directions) will be treated in the same manner as that of ridge ledges, terms (I-i) being replaced by (I+i) in formulas of article 5.332.1.

5.334. SPURS AND PEAKS.

In the case when the relief includes two sides of opposite slopes I1 and I2 separated by intermediary ridges or crests, one will consider, beside individual effects of these changes of slope, the effects of fictitious ridges defined in figure 5.334 and take the envelope of the results.

APPENDIX F
EXCERPT FROM PROPOSED NEW GREEK SEISMIC CODE[4]

The following table, with the quantities B and D defined in the figures, gives a "Foundation Coefficient" that multiplies the usual base shear coefficient, which is already a function of site conditions. Site categories A, B, and C correspond roughly to S1, S2 and S3/S4, respectively.

The new Greek Seismic Code is to be finalized in early 1992. The proposed Eurocode (EC8) contains similar provisions; it is under review and should be ready by 1993.

---

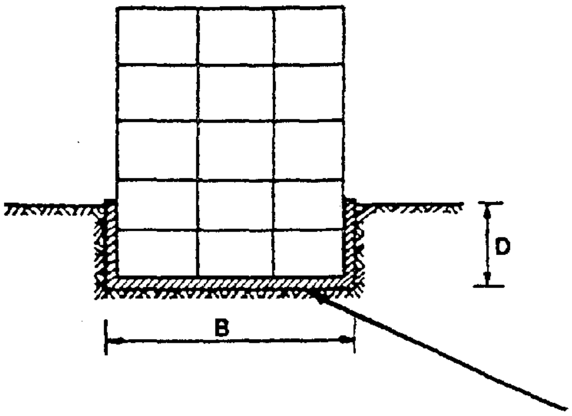
[4] As interpreted by Professor George Gazetas

TABLE F-I Foundation Coefficient (ϑ)
(multiplies the base shear coefficient)

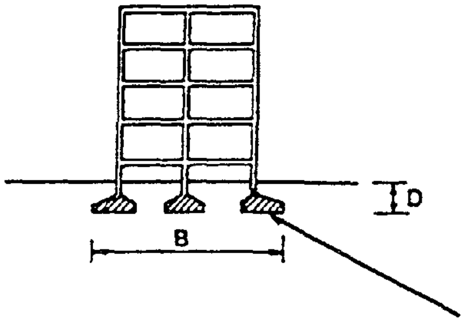
RELATIVE STIFFNESS	RELATIVE DEPTH	SOIL CATEGORY A	SOIL CATEGORY B	SOIL CATEGORY C
Small	small* ($D/B < 0.10$)	1.0	1.1	1.2
	large ($D/B \geq 0.40$)	0.85	0.9	1.0
Large	small ($D/B < 0.10$)	0.85	0.9	1.0
	large ($D/B \geq 0.10$)	0.7	0.8	0.9

* for intermediate depths: interpolate

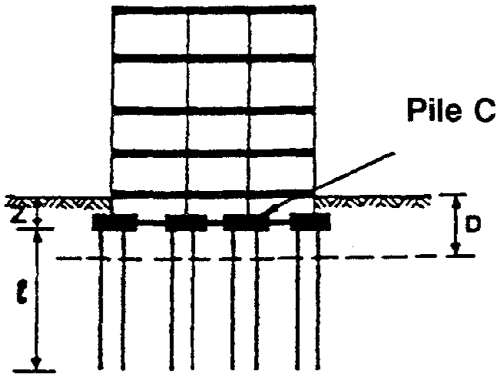
The following sketches explain the meaning of symbols D and B in Table F-I:



Rigid Box Foundation



Isolated Footings



Pile Caps Connected with Tie Beams

$D \leq z + l/5$

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
LIST OF TECHNICAL REPORTS

The National Center for Earthquake Engineering Research (NCEER) publishes technical reports on a variety of subjects related to earthquake engineering written by authors funded through NCEER. These reports are available from both NCEER's Publications Department and the National Technical Information Service (NTIS). Requests for reports should be directed to the Publications Department, National Center for Earthquake Engineering Research, State University of New York at Buffalo, Red Jacket Quadrangle, Buffalo, New York 14261. Reports can also be requested through NTIS, 5285 Port Royal Road, Springfield, Virginia 22161. NTIS accession numbers are shown in parenthesis, if available.

NCEER-87-0001	"First-Year Program in Research, Education and Technology Transfer," 3/5/87, (PB88-134275/AS).
NCEER-87-0002	"Experimental Evaluation of Instantaneous Optimal Algorithms for Structural Control," by R.C. Lin, T.T. Soong and A.M. Reinhorn, 4/20/87, (PB88-134341/AS).
NCEER-87-0003	"Experimentation Using the Earthquake Simulation Facilities at University at Buffalo," by A.M. Reinhorn and R.L. Ketter, to be published.
NCEER-87-0004	"The System Characteristics and Performance of a Shaking Table," by J.S. Hwang, K.C. Chang and G.C. Lee, 6/1/87, (PB88-134259/AS). This report is available only through NTIS (see address given above).
NCEER-87-0005	"A Finite Element Formulation for Nonlinear Viscoplastic Material Using a Q Model," by O. Gyebi and G. Dasgupta, 11/2/87, (PB88-213764/AS).
NCEER-87-0006	"Symbolic Manipulation Program (SMP) - Algebraic Codes for Two and Three Dimensional Finite Element Formulations," by X. Lee and G. Dasgupta, 11/9/87, (PB88-219522/AS).
NCEER-87-0007	"Instantaneous Optimal Control Laws for Tall Buildings Under Seismic Excitations," by J.N. Yang, A. Akbarpour and P. Ghaemmaghami, 6/10/87, (PB88-134333/AS).
NCEER-87-0008	"IDARC: Inelastic Damage Analysis of Reinforced Concrete Frame - Shear-Wall Structures," by Y.J. Park, A.M. Reinhorn and S.K. Kunnath, 7/20/87, (PB88-134325/AS).
NCEER-87-0009	"Liquefaction Potential for New York State: A Preliminary Report on Sites in Manhattan and Buffalo," by M. Budhu, V. Vijayakumar, R.F. Giese and L. Baumgras, 8/31/87, (PB88-163704/AS). This report is available only through NTIS (see address given above).
NCEER-87-0010	"Vertical and Torsional Vibration of Foundations in Inhomogeneous Media," by A.S. Veletsos and K.W. Dotson, 6/1/87, (PB88-134291/AS).
NCEER-87-0011	"Seismic Probabilistic Risk Assessment and Seismic Margins Studies for Nuclear Power Plants," by Howard H.M. Hwang, 6/15/87, (PB88-134267/AS).
NCEER-87-0012	"Parametric Studies of Frequency Response of Secondary Systems Under Ground-Acceleration Excitations," by Y. Yong and Y.K. Lin, 6/10/87, (PB88-134309/AS).
NCEER-87-0013	"Frequency Response of Secondary Systems Under Seismic Excitation," by J.A. HoLung, J. Cai and Y.K. Lin, 7/31/87, (PB88-134317/AS).
NCEER-87-0014	"Modelling Earthquake Ground Motions in Seismically Active Regions Using Parametric Time Series Methods," by G.W. Ellis and A.S. Cakmak, 8/25/87, (PB88-134283/AS).
NCEER-87-0015	"Detection and Assessment of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 8/25/87, (PB88-163712/AS).

NCEER-87-0016 "Pipeline Experiment at Parkfield, California," by J. Isenberg and E. Richardson, 9/15/87, (PB88-163720/AS). This report is available only through NTIS (see address given above).

NCEER-87-0017 "Digital Simulation of Seismic Ground Motion," by M. Shinozuka, G. Deodatis and T. Harada, 8/31/87, (PB88-155197/AS). This report is available only through NTIS (see address given above).

NCEER-87-0018 "Practical Considerations for Structural Control: System Uncertainty, System Time Delay and Truncation of Small Control Forces," J.N. Yang and A. Akbarpour, 8/10/87, (PB88-163738/AS).

NCEER-87-0019 "Modal Analysis of Nonclassically Damped Structural Systems Using Canonical Transformation," by J.N. Yang, S. Sarkani and F.X. Long, 9/27/87, (PB88-187851/AS).

NCEER-87-0020 "A Nonstationary Solution in Random Vibration Theory," by J.R. Red-Horse and P.D. Spanos, 11/3/87, (PB88-163746/AS).

NCEER-87-0021 "Horizontal Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by A.S. Veletsos and K.W. Dotson, 10/15/87, (PB88-150859/AS).

NCEER-87-0022 "Seismic Damage Assessment of Reinforced Concrete Members," by Y.S. Chung, C. Meyer and M. Shinozuka, 10/9/87, (PB88-150867/AS). This report is available only through NTIS (see address given above).

NCEER-87-0023 "Active Structural Control in Civil Engineering," by T.T. Soong, 11/11/87, (PB88-187778/AS).

NCEER-87-0024 "Vertical and Torsional Impedances for Radially Inhomogeneous Viscoelastic Soil Layers," by K.W. Dotson and A.S. Veletsos, 12/87, (PB88-187786/AS).

NCEER-87-0025 "Proceedings from the Symposium on Seismic Hazards, Ground Motions, Soil-Liquefaction and Engineering Practice in Eastern North America," October 20-22, 1987, edited by K.H. Jacob, 12/87, (PB88-188115/AS).

NCEER-87-0026 "Report on the Whittier-Narrows, California, Earthquake of October 1, 1987," by J. Pantelic and A. Reinhorn, 11/87, (PB88-187752/AS). This report is available only through NTIS (see address given above).

NCEER-87-0027 "Design of a Modular Program for Transient Nonlinear Analysis of Large 3-D Building Structures," by S. Srivastav and J.F. Abel, 12/30/87, (PB88-187950/AS).

NCEER-87-0028 "Second-Year Program in Research, Education and Technology Transfer," 3/8/88, (PB88-219480/AS).

NCEER-88-0001 "Workshop on Seismic Computer Analysis and Design of Buildings With Interactive Graphics," by W. McGuire, J.F. Abel and C.H. Conley, 1/18/88, (PB88-187760/AS).

NCEER-88-0002 "Optimal Control of Nonlinear Flexible Structures," by J.N. Yang, F.X. Long and D. Wong, 1/22/88, (PB88-213772/AS).

NCEER-88-0003 "Substructuring Techniques in the Time Domain for Primary-Secondary Structural Systems," by G.D. Manolis and G. Juhn, 2/10/88, (PB88-213780/AS).

NCEER-88-0004 "Iterative Seismic Analysis of Primary-Secondary Systems," by A. Singhal, L.D. Lutes and P.D. Spanos, 2/23/88, (PB88-213798/AS).

NCEER-88-0005 "Stochastic Finite Element Expansion for Random Media," by P.D. Spanos and R. Ghanem, 3/14/88, (PB88-213806/AS).

NCEER-88-0006 "Combining Structural Optimization and Structural Control," by F.Y. Cheng and C.P. Pantelides, 1/10/88, (PB88-213814/AS).

NCEER-88-0007 "Seismic Performance Assessment of Code-Designed Structures," by H.H-M. Hwang, J-W. Jaw and H-J. Shau, 3/20/88, (PB88-219423/AS).

NCEER-88-0008 "Reliability Analysis of Code-Designed Structures Under Natural Hazards," by H.H-M. Hwang, H. Ushiba and M. Shinozuka, 2/29/88, (PB88-229471/AS).

NCEER-88-0009 "Seismic Fragility Analysis of Shear Wall Structures," by J-W Jaw and H.H-M. Hwang, 4/30/88, (PB89-102867/AS).

NCEER-88-0010 "Base Isolation of a Multi-Story Building Under a Harmonic Ground Motion - A Comparison of Performances of Various Systems," by F-G Fan, G. Ahmadi and I.G. Tadjbakhsh, 5/18/88, (PB89-122238/AS).

NCEER-88-0011 "Seismic Floor Response Spectra for a Combined System by Green's Functions," by F.M. Lavelle, L.A. Bergman and P.D. Spanos, 5/1/88, (PB89-102875/AS).

NCEER-88-0012 "A New Solution Technique for Randomly Excited Hysteretic Structures," by G.Q. Cai and Y.K. Lin, 5/16/88, (PB89-102883/AS).

NCEER-88-0013 "A Study of Radiation Damping and Soil-Structure Interaction Effects in the Centrifuge," by K. Weissman, supervised by J.H. Prevost, 5/24/88, (PB89-144703/AS).

NCEER-88-0014 "Parameter Identification and Implementation of a Kinematic Plasticity Model for Frictional Soils," by J.H. Prevost and D.V. Griffiths, to be published.

NCEER-88-0015 "Two- and Three- Dimensional Dynamic Finite Element Analyses of the Long Valley Dam," by D.V. Griffiths and J.H. Prevost, 6/17/88, (PB89-144711/AS).

NCEER-88-0016 "Damage Assessment of Reinforced Concrete Structures in Eastern United States," by A.M. Reinhorn, M.J. Seidel, S.K. Kunnath and Y.J. Park, 6/15/88, (PB89-122220/AS).

NCEER-88-0017 "Dynamic Compliance of Vertically Loaded Strip Foundations in Multilayered Viscoelastic Soils," by S. Ahmad and A.S.M. Israil, 6/17/88, (PB89-102891/AS).

NCEER-88-0018 "An Experimental Study of Seismic Structural Response With Added Viscoelastic Dampers," by R.C. Lin, Z. Liang, T.T. Soong and R.H. Zhang, 6/30/88, (PB89-122212/AS). This report is available only through NTIS (see address given above).

NCEER-88-0019 "Experimental Investigation of Primary - Secondary System Interaction," by G.D. Manolis, G. Juhn and A.M. Reinhorn, 5/27/88, (PB89-122204/AS).

NCEER-88-0020 "A Response Spectrum Approach For Analysis of Nonclassically Damped Structures," by J.N. Yang, S. Sarkani and F.X. Long, 4/22/88, (PB89-102909/AS).

NCEER-88-0021 "Seismic Interaction of Structures and Soils: Stochastic Approach," by A.S. Veletsos and A.M. Prasad, 7/21/88, (PB89-122196/AS).

NCEER-88-0022 "Identification of the Serviceability Limit State and Detection of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 6/15/88, (PB89-122188/AS). This report is available only through NTIS (see address given above).

NCEER-88-0023 "Multi-Hazard Risk Analysis: Case of a Simple Offshore Structure," by B.K. Bhartia and E.H. Vanmarcke, 7/21/88, (PB89-145213/AS).

NCEER-88-0024	"Automated Seismic Design of Reinforced Concrete Buildings," by Y.S. Chung, C. Meyer and M. Shinozuka, 7/5/88, (PB89-122170/AS). This report is available only through NTIS (see address given above).
NCEER-88-0025	"Experimental Study of Active Control of MDOF Structures Under Seismic Excitations," by L.L. Chung, R.C. Lin, T.T. Soong and A.M. Reinhorn, 7/10/88, (PB89-122600/AS).
NCEER-88-0026	"Earthquake Simulation Tests of a Low-Rise Metal Structure," by J.S. Hwang, K.C. Chang, G.C. Lee and R.L. Ketter, 8/1/88, (PB89-102917/AS).
NCEER-88-0027	"Systems Study of Urban Response and Reconstruction Due to Catastrophic Earthquakes," by F. Kozin and H.K. Zhou, 9/22/88, (PB90-162348/AS).
NCEER-88-0028	"Seismic Fragility Analysis of Plane Frame Structures," by H.H-M. Hwang and Y.K. Low, 7/31/88, (PB89-131445/AS).
NCEER-88-0029	"Response Analysis of Stochastic Structures," by A. Kardara, C. Bucher and M. Shinozuka, 9/22/88, (PB89-174429/AS).
NCEER-88-0030	"Nonnormal Accelerations Due to Yielding in a Primary Structure," by D.C.K. Chen and L.D. Lutes, 9/19/88, (PB89-131437/AS).
NCEER-88-0031	"Design Approaches for Soil-Structure Interaction," by A.S. Veletsos, A.M. Prasad and Y. Tang, 12/30/88, (PB89-174437/AS). This report is available only through NTIS (see address given above).
NCEER-88-0032	"A Re-evaluation of Design Spectra for Seismic Damage Control," by C.J. Turkstra and A.G. Tallin, 11/7/88, (PB89-145221/AS).
NCEER-88-0033	"The Behavior and Design of Noncontact Lap Splices Subjected to Repeated Inelastic Tensile Loading," by V.E. Sagan, P. Gergely and R.N. White, 12/8/88, (PB89-163737/AS).
NCEER-88-0034	"Seismic Response of Pile Foundations," by S.M. Mamoon, P.K. Banerjee and S. Ahmad, 11/1/88, (PB89-145239/AS).
NCEER-88-0035	"Modeling of R/C Building Structures With Flexible Floor Diaphragms (IDARC2)," by A.M. Reinhorn, S.K. Kunnath and N. Panahshahi, 9/7/88, (PB89-207153/AS).
NCEER-88-0036	"Solution of the Dam-Reservoir Interaction Problem Using a Combination of FEM, BEM with Particular Integrals, Modal Analysis, and Substructuring," by C-S. Tsai, G.C. Lee and R.L. Ketter, 12/31/88, (PB89-207146/AS).
NCEER-88-0037	"Optimal Placement of Actuators for Structural Control," by F.Y. Cheng and C.P. Pantelides, 8/15/88, (PB89-162846/AS).
NCEER-88-0038	"Teflon Bearings in Aseismic Base Isolation: Experimental Studies and Mathematical Modeling," by A. Mokha, M.C. Constantinou and A.M. Reinhorn, 12/5/88, (PB89-218457/AS). This report is available only through NTIS (see address given above).
NCEER-88-0039	"Seismic Behavior of Flat Slab High-Rise Buildings in the New York City Area," by P. Weidlinger and M. Ettouney, 10/15/88, (PB90-145681/AS).
NCEER-88-0040	"Evaluation of the Earthquake Resistance of Existing Buildings in New York City," by P. Weidlinger and M. Ettouney, 10/15/88, to be published.
NCEER-88-0041	"Small-Scale Modeling Techniques for Reinforced Concrete Structures Subjected to Seismic Loads," by W. Kim, A. El-Attar and R.N. White, 11/22/88, (PB89-189625/AS).

NCEER-88-0042	"Modeling Strong Ground Motion from Multiple Event Earthquakes," by G.W. Ellis and A.S. Cakmak, 10/15/88, (PB89-174445/AS).
NCEER-88-0043	"Nonstationary Models of Seismic Ground Acceleration," by M. Grigoriu, S.E. Ruiz and E. Rosenblueth, 7/15/88, (PB89-189617/AS).
NCEER-88-0044	"SARCF User's Guide: Seismic Analysis of Reinforced Concrete Frames," by Y.S. Chung, C. Meyer and M. Shinozuka, 11/9/88, (PB89-174452/AS).
NCEER-88-0045	"First Expert Panel Meeting on Disaster Research and Planning," edited by J. Pantelic and J. Stoyle, 9/15/88, (PB89-174460/AS).
NCEER-88-0046	"Preliminary Studies of the Effect of Degrading Infill Walls on the Nonlinear Seismic Response of Steel Frames," by C.Z. Chrysostomou, P. Gergely and J.F. Abel, 12/19/88, (PB89-208383/AS).
NCEER-88-0047	"Reinforced Concrete Frame Component Testing Facility - Design, Construction, Instrumentation and Operation," by S.P. Pessiki, C. Conley, T. Bond, P. Gergely and R.N. White, 12/16/88, (PB89-174478/AS).
NCEER-89-0001	"Effects of Protective Cushion and Soil Compliancy on the Response of Equipment Within a Seismically Excited Building," by J.A. HoLung, 2/16/89, (PB89-207179/AS).
NCEER-89-0002	"Statistical Evaluation of Response Modification Factors for Reinforced Concrete Structures," by H.H-M. Hwang and J-W. Jaw, 2/17/89, (PB89-207187/AS).
NCEER-89-0003	"Hysteretic Columns Under Random Excitation," by G-Q. Cai and Y.K. Lin, 1/9/89, (PB89-196513/AS).
NCEER-89-0004	"Experimental Study of 'Elephant Foot Bulge' Instability of Thin-Walled Metal Tanks," by Z-H. Jia and R.L. Ketter, 2/22/89, (PB89-207195/AS).
NCEER-89-0005	"Experiment on Performance of Buried Pipelines Across San Andreas Fault," by J. Isenberg, E. Richardson and T.D. O'Rourke, 3/10/89, (PB89-218440/AS).
NCEER-89-0006	"A Knowledge-Based Approach to Structural Design of Earthquake-Resistant Buildings," by M. Subramani, P. Gergely, C.H. Conley, J.F. Abel and A.H. Zaghw, 1/15/89, (PB89-218465/AS).
NCEER-89-0007	"Liquefaction Hazards and Their Effects on Buried Pipelines," by T.D. O'Rourke and P.A. Lane, 2/1/89, (PB89-218481).
NCEER-89-0008	"Fundamentals of System Identification in Structural Dynamics," by H. Imai, C-B. Yun, O. Maruyama and M. Shinozuka, 1/26/89, (PB89-207211/AS).
NCEER-89-0009	"Effects of the 1985 Michoacan Earthquake on Water Systems and Other Buried Lifelines in Mexico," by A.G. Ayala and M.J. O'Rourke, 3/8/89, (PB89-207229/AS).
NCEER-89-R010	"NCEER Bibliography of Earthquake Education Materials," by K.E.K. Ross, Second Revision, 9/1/89, (PB90-125352/AS).
NCEER-89-0011	"Inelastic Three-Dimensional Response Analysis of Reinforced Concrete Building Structures (IDARC-3D), Part I - Modeling," by S.K. Kunnath and A.M. Reinhorn, 4/17/89, (PB90-114612/AS).
NCEER-89-0012	"Recommended Modifications to ATC-14," by C.D. Poland and J.O. Malley, 4/12/89, (PB90-108648/AS).
NCEER-89-0013	"Repair and Strengthening of Beam-to-Column Connections Subjected to Earthquake Loading," by M. Corazao and A.J. Durrani, 2/28/89, (PB90-109885/AS).

NCEER-89-0014	"Program EXKAL2 for Identification of Structural Dynamic Systems," by O. Maruyama, C-B. Yun, M. Hoshiya and M. Shinozuka, 5/19/89, (PB90-109877/AS).
NCEER-89-0015	"Response of Frames With Bolted Semi-Rigid Connections, Part I - Experimental Study and Analytical Predictions," by P.J. DiCorso, A.M. Reinhorn, J.R. Dickerson, J.B. Radziminski and W.L. Harper, 6/1/89, to be published.
NCEER-89-0016	"ARMA Monte Carlo Simulation in Probabilistic Structural Analysis," by P.D. Spanos and M.P. Mignolet, 7/10/89, (PB90-109893/AS).
NCEER-89-P017	"Preliminary Proceedings from the Conference on Disaster Preparedness - The Place of Earthquake Education in Our Schools," Edited by K.E.K. Ross, 6/23/89.
NCEER-89-0017	"Proceedings from the Conference on Disaster Preparedness - The Place of Earthquake Education in Our Schools," Edited by K.E.K. Ross, 12/31/89, (PB90-207895). This report is available only through NTIS (see address given above).
NCEER-89-0018	"Multidimensional Models of Hysteretic Material Behavior for Vibration Analysis of Shape Memory Energy Absorbing Devices, by E.J. Graesser and F.A. Cozzarelli, 6/7/89, (PB90-164146/AS).
NCEER-89-0019	"Nonlinear Dynamic Analysis of Three-Dimensional Base Isolated Structures (3D-BASIS)," by S. Nagarajaiah, A.M. Reinhorn and M.C. Constantinou, 8/3/89, (PB90-161936/AS). This report is available only through NTIS (see address given above).
NCEER-89-0020	"Structural Control Considering Time-Rate of Control Forces and Control Rate Constraints," by F.Y. Cheng and C.P. Pantelides, 8/3/89, (PB90-120445/AS).
NCEER-89-0021	"Subsurface Conditions of Memphis and Shelby County," by K.W. Ng, T-S. Chang and H-H.M. Hwang, 7/26/89, (PB90-120437/AS).
NCEER-89-0022	"Seismic Wave Propagation Effects on Straight Jointed Buried Pipelines," by K. Elhmadi and M.J. O'Rourke, 8/24/89, (PB90-162322/AS).
NCEER-89-0023	"Workshop on Serviceability Analysis of Water Delivery Systems," edited by M. Grigoriu, 3/6/89, (PB90-127424/AS).
NCEER-89-0024	"Shaking Table Study of a 1/5 Scale Steel Frame Composed of Tapered Members," by K.C. Chang, J.S. Hwang and G.C. Lee, 9/18/89, (PB90-160169/AS).
NCEER-89-0025	"DYNA1D: A Computer Program for Nonlinear Seismic Site Response Analysis - Technical Documentation," by Jean H. Prevost, 9/14/89, (PB90-161944/AS). This report is available only through NTIS (see address given above).
NCEER-89-0026	"1:4 Scale Model Studies of Active Tendon Systems and Active Mass Dampers for Aseismic Protection," by A.M. Reinhorn, T.T. Soong, R.C. Lin, Y.P. Yang, Y. Fukao, H. Abe and M. Nakai, 9/15/89, (PB90-173246/AS).
NCEER-89-0027	"Scattering of Waves by Inclusions in a Nonhomogeneous Elastic Half Space Solved by Boundary Element Methods," by P.K. Hadley, A. Askar and A.S. Cakmak, 6/15/89, (PB90-145699/AS).
NCEER-89-0028	"Statistical Evaluation of Deflection Amplification Factors for Reinforced Concrete Structures," by H.H.M. Hwang, J-W. Jaw and A.L. Ch'ng, 8/31/89, (PB90-164633/AS).
NCEER-89-0029	"Bedrock Accelerations in Memphis Area Due to Large New Madrid Earthquakes," by H.H.M. Hwang, C.H.S. Chen and G. Yu, 11/7/89, (PB90-162330/AS).

NCEER-89-0030 "Seismic Behavior and Response Sensitivity of Secondary Structural Systems," by Y.Q. Chen and T.T. Soong, 10/23/89, (PB90-164658/AS).

NCEER-89-0031 "Random Vibration and Reliability Analysis of Primary-Secondary Structural Systems," by Y. Ibrahim, M. Grigoriu and T.T. Soong, 11/10/89, (PB90-161951/AS).

NCEER-89-0032 "Proceedings from the Second U.S. - Japan Workshop on Liquefaction, Large Ground Deformation and Their Effects on Lifelines, September 26-29, 1989," Edited by T.D. O'Rourke and M. Hamada, 12/1/89, (PB90-209388/AS).

NCEER-89-0033 "Deterministic Model for Seismic Damage Evaluation of Reinforced Concrete Structures," by J.M. Bracci, A.M. Reinhorn, J.B. Mander and S.K. Kunnath, 9/27/89.

NCEER-89-0034 "On the Relation Between Local and Global Damage Indices," by E. DiPasquale and A.S. Cakmak, 8/15/89, (PB90-173865).

NCEER-89-0035 "Cyclic Undrained Behavior of Nonplastic and Low Plasticity Silts," by A.J. Walker and H.E. Stewart, 7/26/89, (PB90-183518/AS).

NCEER-89-0036 "Liquefaction Potential of Surficial Deposits in the City of Buffalo, New York," by M. Budhu, R. Giese and L. Baumgrass, 1/17/89, (PB90-208455/AS).

NCEER-89-0037 "A Determinstic Assessment of Effects of Ground Motion Incoherence," by A.S. Veletsos and Y. Tang, 7/15/89, (PB90-164294/AS).

NCEER-89-0038 "Workshop on Ground Motion Parameters for Seismic Hazard Mapping," July 17-18, 1989, edited by R.V. Whitman, 12/1/89, (PB90-173923/AS).

NCEER-89-0039 "Seismic Effects on Elevated Transit Lines of the New York City Transit Authority," by C.J. Costantino, C.A. Miller and E. Heymsfield, 12/26/89, (PB90-207887/AS).

NCEER-89-0040 "Centrifugal Modeling of Dynamic Soil-Structure Interaction," by K. Weissman, Supervised by J.H. Prevost, 5/10/89, (PB90-207879/AS).

NCEER-89-0041 "Linearized Identification of Buildings With Cores for Seismic Vulnerability Assessment," by I-K. Ho and A.E. Aktan, 11/1/89, (PB90-251943/AS).

NCEER-90-0001 "Geotechnical and Lifeline Aspects of the October 17, 1989 Loma Prieta Earthquake in San Francisco," by T.D. O'Rourke, H.E. Stewart, F.T. Blackburn and T.S. Dickerman, 1/90, (PB90-208596/AS).

NCEER-90-0002 "Nonnormal Secondary Response Due to Yielding in a Primary Structure," by D.C.K. Chen and L.D. Lutes, 2/28/90, (PB90-251976/AS).

NCEER-90-0003 "Earthquake Education Materials for Grades K-12," by K.E.K. Ross, 4/16/90, (PB91-113415/AS).

NCEER-90-0004 "Catalog of Strong Motion Stations in Eastern North America," by R.W. Busby, 4/3/90, (PB90-251984)/AS.

NCEER-90-0005 "NCEER Strong-Motion Data Base: A User Manuel for the GeoBase Release (Version 1.0 for the Sun3)," by P. Friberg and K. Jacob, 3/31/90 (PB90-258062/AS).

NCEER-90-0006 "Seismic Hazard Along a Crude Oil Pipeline in the Event of an 1811-1812 Type New Madrid Earthquake," by H.H.M. Hwang and C-H.S. Chen, 4/16/90(PB90-258054).

NCEER-90-0007 "Site-Specific Response Spectra for Memphis Sheahan Pumping Station," by H.H.M. Hwang and C.S. Lee, 5/15/90, (PB91-108811/AS).

NCEER-90-0008	"Pilot Study on Seismic Vulnerability of Crude Oil Transmission Systems," by T. Ariman, R. Dobry, M. Grigoriu, F. Kozin, M. O'Rourke, T. O'Rourke and M. Shinozuka, 5/25/90, (PB91-108837/AS).
NCEER-90-0009	"A Program to Generate Site Dependent Time Histories: EQGEN," by G.W. Ellis, M. Srinivasan and A.S. Cakmak, 1/30/90, (PB91-108829/AS).
NCEER-90-0010	"Active Isolation for Seismic Protection of Operating Rooms," by M.E. Talbott, Supervised by M. Shinozuka, 6/8/9, (PB91-110205/AS).
NCEER-90-0011	"Program LINEARID for Identification of Linear Structural Dynamic Systems," by C-B. Yun and M. Shinozuka, 6/25/90, (PB91-110312/AS).
NCEER-90-0012	"Two-Dimensional Two-Phase Elasto-Plastic Seismic Response of Earth Dams," by A.N. Yiagos, Supervised by J.H. Prevost, 6/20/90, (PB91-110197/AS).
NCEER-90-0013	"Secondary Systems in Base-Isolated Structures: Experimental Investigation, Stochastic Response and Stochastic Sensitivity," by G.D. Manolis, G. Juhn, M.C. Constantinou and A.M. Reinhorn, 7/1/90, (PB91-110320/AS).
NCEER-90-0014	"Seismic Behavior of Lightly-Reinforced Concrete Column and Beam-Column Joint Details," by S.P. Pessiki, C.H. Conley, P. Gergely and R.N. White, 8/22/90, (PB91-108795/AS).
NCEER-90-0015	"Two Hybrid Control Systems for Building Structures Under Strong Earthquakes," by J.N. Yang and A. Danielians, 6/29/90, (PB91-125393/AS).
NCEER-90-0016	"Instantaneous Optimal Control with Acceleration and Velocity Feedback," by J.N. Yang and Z. Li, 6/29/90, (PB91-125401/AS).
NCEER-90-0017	"Reconnaissance Report on the Northern Iran Earthquake of June 21, 1990," by M. Mehrain, 10/4/90, (PB91-125377/AS).
NCEER-90-0018	"Evaluation of Liquefaction Potential in Memphis and Shelby County," by T.S. Chang, P.S. Tang, C.S. Lee and H. Hwang, 8/10/90, (PB91-125427/AS).
NCEER-90-0019	"Experimental and Analytical Study of a Combined Sliding Disc Bearing and Helical Steel Spring Isolation System," by M.C. Constantinou, A.S. Mokha and A.M. Reinhorn, 10/4/90, (PB91-125385/AS).
NCEER-90-0020	"Experimental Study and Analytical Prediction of Earthquake Response of a Sliding Isolation System with a Spherical Surface," by A.S. Mokha, M.C. Constantinou and A.M. Reinhorn, 10/11/90, (PB91-125419/AS).
NCEER-90-0021	"Dynamic Interaction Factors for Floating Pile Groups," by G. Gazetas, K. Fan, A. Kaynia and E. Kausel, 9/10/90, (PB91-170381/AS).
NCEER-90-0022	"Evaluation of Seismic Damage Indices for Reinforced Concrete Structures," by S. Rodriguez-Gomez and A.S. Cakmak, 9/30/90, PB91-171322/AS).
NCEER-90-0023	"Study of Site Response at a Selected Memphis Site," by H. Desai, S. Ahmad, E.S. Gazetas and M.R. Oh, 10/11/90, (PB91-196857/AS).
NCEER-90-0024	"A User's Guide to Strongmo: Version 1.0 of NCEER's Strong-Motion Data Access Tool for PCs and Terminals," by P.A. Friberg and C.A.T. Susch, 11/15/90, (PB91-171272/AS).
NCEER-90-0025	"A Three-Dimensional Analytical Study of Spatial Variability of Seismic Ground Motions," by L-L. Hong and A.H.-S. Ang, 10/30/90, (PB91-170399/AS).

NCEER-90-0026	"MUMOID User's Guide - A Program for the Identification of Modal Parameters," by S. Rodriguez-Gomez and E. DiPasquale, 9/30/90, (PB91-171298/AS).
NCEER-90-0027	"SARCF-II User's Guide - Seismic Analysis of Reinforced Concrete Frames," by S. Rodriguez-Gomez, Y.S. Chung and C. Meyer, 9/30/90, (PB91-171280/AS).
NCEER-90-0028	"Viscous Dampers: Testing, Modeling and Application in Vibration and Seismic Isolation," by N. Makris and M.C. Constantinou, 12/20/90 (PB91-190561/AS).
NCEER-90-0029	"Soil Effects on Earthquake Ground Motions in the Memphis Area," by H. Hwang, C.S. Lee, K.W. Ng and T.S. Chang, 8/2/90, (PB91-190751/AS).
NCEER-91-0001	"Proceedings from the Third Japan-U.S. Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures for Soil Liquefaction, December 17-19, 1990," edited by T.D. O'Rourke and M. Hamada, 2/1/91, (PB91-179259/AS).
NCEER-91-0002	"Physical Space Solutions of Non-Proportionally Damped Systems," by M. Tong, Z. Liang and G.C. Lee, 1/15/91, (PB91-179242/AS).
NCEER-91-0003	"Seismic Response of Single Piles and Pile Groups," by K. Fan and G. Gazetas, 1/10/91.
NCEER-91-0004	"Damping of Structures: Part 1 - Theory of Complex Damping," by Z. Liang and G. Lee, 10/10/91.
NCEER-91-0005	"3D-BASIS - Nonlinear Dynamic Analysis of Three Dimensional Base Isolated Structures: Part II," by S. Nagarajaiah, A.M. Reinhorn and M.C. Constantinou, 2/28/91, (PB91-190553/AS).
NCEER-91-0006	"A Multidimensional Hysteretic Model for Plasticity Deforming Metals in Energy Absorbing Devices," by E.J. Graesser and F.A. Cozzarelli, 4/9/91.
NCEER-91-0007	"A Framework for Customizable Knowledge-Based Expert Systems with an Application to a KBES for Evaluating the Seismic Resistance of Existing Buildings," by E.G. Ibarra-Anaya and S.J. Fenves, 4/9/91, (PB91-210930/AS).
NCEER-91-0008	"Nonlinear Analysis of Steel Frames with Semi-Rigid Connections Using the Capacity Spectrum Method," by G.G. Deierlein, S-H. Hsieh, Y-J. Shen and J.F. Abel, 7/2/91, (PB92-113828/AS).
NCEER-91-0009	"Earthquake Education Materials for Grades K-12," by K.E.K. Ross, 4/30/91, (PB91-212142/AS).
NCEER-91-0010	"Phase Wave Velocities and Displacement Phase Differences in a Harmonically Oscillating Pile," by N. Makris and G. Gazetas, 7/8/91, (PB92-108356/AS).
NCEER-91-0011	"Dynamic Characteristics of a Full-Sized Five-Story Steel Structure and a 2/5 Model," by K.C. Chang, G.C. Yao, G.C. Lee, D.S. Hao and Y.C. Yeh," to be published.
NCEER-91-0012	"Seismic Response of a 2/5 Scale Steel Structure with Added Viscoelastic Dampers," by K.C. Chang, T.T. Soong, S-T. Oh and M.L. Lai, 5/17/91 (PB92-110816/AS).
NCEER-91-0013	"Earthquake Response of Retaining Walls; Full-Scale Testing and Computational Modeling," by S. Alampalli and A-W.M. Elgamal, 6/20/91, to be published.
NCEER-91-0014	"3D-BASIS-M: Nonlinear Dynamic Analysis of Multiple Building Base Isolated Structures," by P.C. Tsopelas, S. Nagarajaiah, M.C. Constantinou and A.M. Reinhorn, 5/28/91, (PB92-113885/AS).
NCEER-91-0015	"Evaluation of SEAOC Design Requirements for Sliding Isolated Structures," by D. Theodossiou and M.C. Constantinou, 6/10/91, (PB92-114602/AS).

NCEER-91-0016	"Closed-Loop Modal Testing of a 27-Story Reinforced Concrete Flat Plate-Core Building," by H.R. Somaprasad, T. Toksoy, H. Yoshiyuki and A.E. Aktan, 7/15/91, (PB92-129980/AS).
NCEER-91-0017	"Shake Table Test of a 1/6 Scale Two-Story Lightly Reinforced Concrete Building," by A.G. El-Attar, R.N. White and P. Gergely, 2/28/91, to be published.
NCEER-91-0018	"Shake Table Test of a 1/8 Scale Three-Story Lightly Reinforced Concrete Building," by A.G. El-Attar, R.N. White and P. Gergely, 2/28/91, to be published.
NCEER-91-0019	"Transfer Functions for Rigid Rectangular Foundations," by A.S. Veletsos, A.M. Prasad and W.H. Wu, 7/31/91, to be published.
NCEER-91-0020	"Hybrid Control of Seismic-Excited Nonlinear and Inelastic Structural Systems," by J.N. Yang, Z. Li and A. Danielians, 8/1/91.
NCEER-91-0021	"The NCEER-91 Earthquake Catalog: Improved Intensity-Based Magnitudes and Recurrence Relations for U.S. Earthquakes East of New Madrid," by L. Seeber and J.G. Armbruster, 8/28/91.
NCEER-91-0022	"Proceedings from the Implementation of Earthquake Planning and Education in Schools: The Need for Change - The Roles of the Changemakers," by K.E.K. Ross and F. Winslow, 7/23/91, (PB92-129998/AS).
NCEER-91-0023	"A Study of Reliability-Based Criteria for Seismic Design of Reinforced Concrete Frame Buildings," by H.H.M. Hwang and H-M. Hsu, 8/10/91.
NCEER-91-0024	"Experimental Verification of a Number of Structural System Identification Algorithms," by R.G. Ghanem, H. Gavin and M. Shinozuka, 9/18/91.
NCEER-91-0025	"Probabilistic Evaluation of Liquefaction Potential," by H.H.M. Hwang and C.S. Lee," 11/25/91.
NCEER-91-0026	"Instantaneous Optimal Control for Linear, Nonlinear and Hysteretic Structures - Stable Controllers," by J.N. Yang and Z. Li, 11/15/91.
NCEER-91-0027	"Experimental and Theoretical Study of a Sliding Isolation System for Bridges," by M.C. Constantinou, A. Kartoum, A.M. Reinhorn and P. Bradford, 11/15/91.
NCEER-92-0001	"Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes, Volume 1: Japanese Case Studies," Edited by M. Hamada and T. O'Rourke, 2/17/92.
NCEER-92-0002	"Case Studies of Liquefaction and Lifeline Performance During Past Earthquakes, Volume 2: United States Case Studies," Edited by T. O'Rourke and M. Hamada, 2/17/92.
NCEER-92-0003	"Issues in Earthquake Education," Edited by K. Ross, to be published.
NCEER-92-0004	"Proceedings from the First U.S. - Japan Workshop on Earthquake Protective Systems for Bridges," 2/4/92, to be published.
NCEER-92-0005	"Seismic Ground Motion from a Haskell-Type Source in a Multiple-Layered Half-Space," A.P. Theoharis, G. Deodatis and M. Shinozuka, 1/2/92, to be published.
NCEER-92-0006	"Proceedings from the Site Effects Workshop," Edited by R. Whitman, 2/29/92.