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from the
Site Effects Workshop**

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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.

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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)

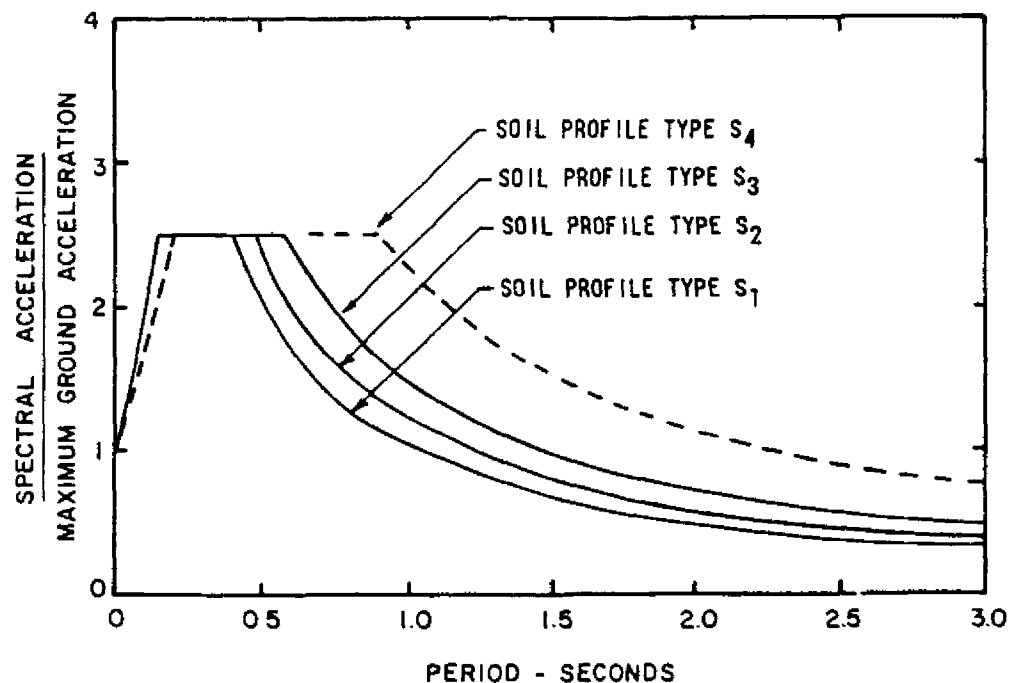
**TABLE NO. 23-J
SITE COEFFICIENTS¹**

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.

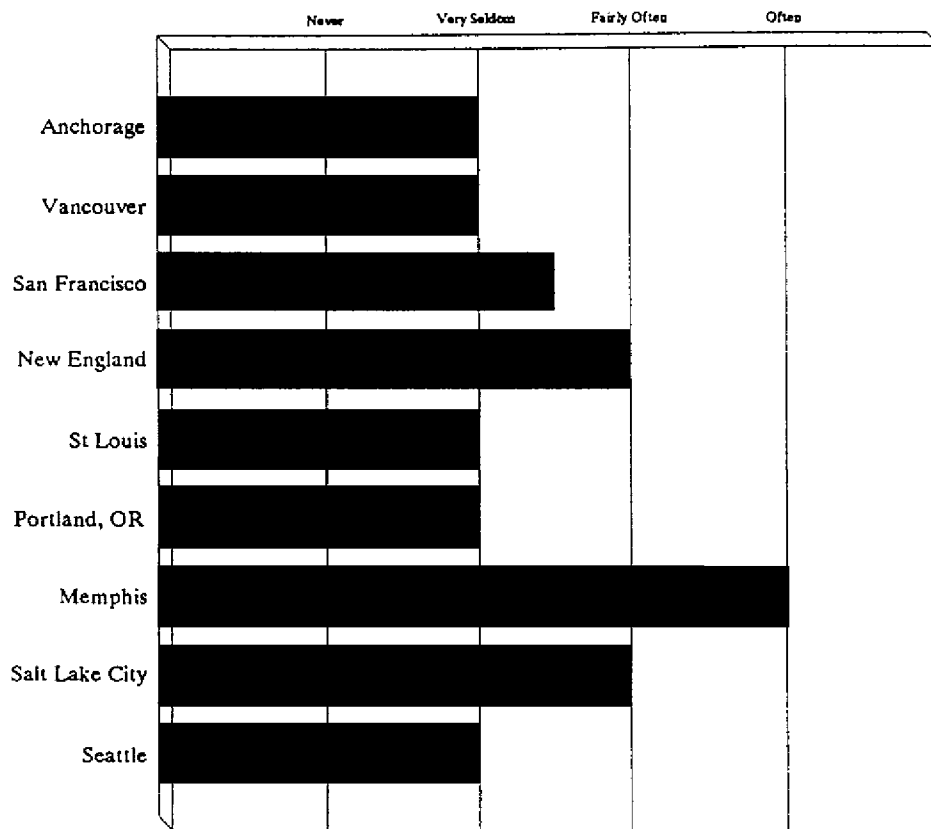
The expanded set of site categories (Figure 2-5) was retained in the final version of the proposed seismic provisions, and blow counts were kept as partial quantitative descriptors. However, the extended quantitative descriptions (Figure 2-7) were dropped.

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)

<u>Type</u>	<u>Description</u>	<u>S-Factor</u>
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 descriptions 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

<u>UBC'88 (for NYC)</u>	<u>Proposed NYC Building Code</u>
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 ≤ 2.75	C ≤ 2.75

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

	<u>UBC'88 for NYC</u> (as inferred from Fig 3, p.179 of UBC'88)	<u>Proposed NYC Code</u>
a)	So=not used S1 = 1.0 S2 ≈ 1.5 S3 ≈ 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)	$S_n = 1 + kT \leq C$ for $T \leq 0.2s$ k=10 for S1 and S2 k= 6.7 for S3	$S_n = 1 + k'T/S_i \leq C$ for $T \leq 0.2s$ k'=20 for all soil profiles
c)	$S_n = S_i / T \leq C$ for $T \geq 0.2s$ Note: use with caution for $T \geq 3s$	$S_n = S_i / T \leq C$ for $T \geq 0.2s$ Note: use with caution for $T \geq 3s$
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)

<u>Type</u>	<u>Thickness</u> (feet)	<u>Description</u> (for Definition of Material Class see appended Note 1, and for Velocity V^* and Blow Count N^* see Note 5)	<u>S-Factor</u>
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) $N^* = D / \sum (d_i / N_i)$ and $D = \sum d_i$,
 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) $V^* = D / \sum (d_i / v_i)$ and $D = \sum d_i$,
 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
10-65	Silts and Silty Soils	Soft	needs special analysis
		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 (SEAOOC) 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 SEAOOC 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 (à 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 NCEEER (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.