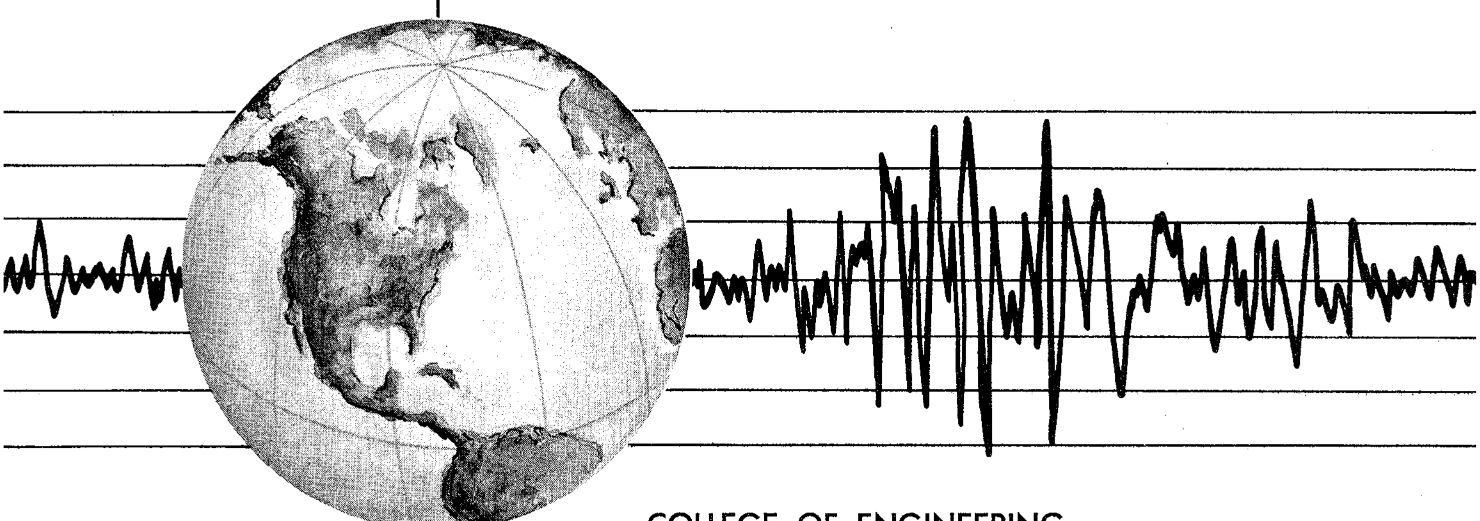
REPORT NO.
UCB/EERC-84/16
OCTOBER 1984

EARTHQUAKE ENGINEERING RESEARCH CENTER

SIMPLIFIED PROCEDURES FOR THE EVALUATION OF SETTLEMENTS IN CLEAN SANDS

by
KOHJI TOKIMATSU
H. BOLTON SEED

A report on research sponsored by
the National Science Foundation



COLLEGE OF ENGINEERING

UNIVERSITY OF CALIFORNIA · Berkeley, California

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/CEE-84027	2.	3. Recipient's Accession No. PB85 197887 /AS

4. Title and Subtitle Simplified Procedures for the Evaluation of Settlements in Sands due to Earthquake Shaking	5. Report Date October 1984
	6.
7. Author(s) Kohji Tokimatsu and H. Bolton Seed	8. Performing Organization Rept. No. UCB/EERC- 84/16
9. Performing Organization Name and Address Earthquake Engineering Research Center University of California, Berkeley 1301 So. 46th Street Richmond, Calif. 94804	10. Project/Task/Work Unit No.
	11. Contract(C) or Grant(G) No. (C) (G) CEE-8110734
12. Sponsoring Organization Name and Address National Science Foundation 1800 G Street, N.W. Washington, D.C. 20550	13. Type of Report & Period Covered
	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

On the basis of previous studies it appears that the primary factors controlling earthquake-induced settlement are the cyclic stress ratio for saturated sands with pore pressure generation and the cyclic shear strain for dry or partially saturated sands, together with the N-value for the sand and the magnitude of the earthquake. This report reviews previous studies, summarizes available information concerning the settlements of sands during earthquakes and proposes simplified methods of analysis to predict earthquake-induced settlement in both saturated and nonsaturated clean sands.

Although the error associated with the estimation of settlements in sands is of the order of ±25 to 50% even for static loading conditions, comparison of the numerical results with several case histories indicates that the methods presented in this report can be used in many cases as a first approximation for evaluating the volume changes and settlements of sands due to earthquake shaking.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement:	19. Security Class (This Report)	21. No. of Pages
Release Unlimited		48
	20. Security Class (This Page)	22. Price

(See ANSI–Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4–77) (Formerly NTIS–35)

SIMPLIFIED PROCEDURES FOR THE EVALUATION OF SETTLEMENTS IN CLEAN SANDS

by

Kohji Tokimatsu
and
H. Bolton Seed

Report No. UCB/EERC-84/16

ERRATA

Page 6, Equation (1) should read:

$$\frac{\tau_{av}}{\sigma_o'} = 0.65 \cdot \frac{a_{max}}{g} \cdot \frac{\sigma_o}{\sigma_o'} \cdot r_d \qquad (1)$$

Page 22, Equation (6) should read:

$$\gamma_{eff}\left(\frac{G_{eff}}{G_{max}}\right) = \frac{0.65 \cdot a_{max} \cdot \sigma_o \cdot r_d}{g \cdot G_{max}} \qquad (6)$$

EARTHQUAKE ENGINEERING RESEARCH CENTER

SIMPLIFIED PROCEDURES FOR THE EVALUATION OF SETTLEMENTS IN SANDS DUE TO EARTHQUAKE SHAKING

by

Kohji Tokimatsu

and

H. Bolton Seed

Report No. UCB/EERC-84/16

October 1984

A report on research sponsored by
the National Science Foundation

College of Engineering
University of California
Berkeley, California

Simplified Procedures for the Evaluation of Settlements in Clean Sands Due to Earthquake Shaking

by Kohji Tokimatsu[1] and H. Bolton Seed[2]

Introduction

It has long been recognized that sands tend to settle and densify when they are subjected to earthquake shaking. If the sand is saturated and there is no possibility for drainage, so that constant volume conditions are maintained, the primary cause of the shaking is the generation of excess pore water pressures. Settlement then occurs as the excess pore pressures dissipate. Depending on the characteristics of the soil and the length of the drainage path, the time required for all settlement to develop can vary considerably, varying from almost immediately to about a day. In dry sands, on the other hand, the settlement occurs during the earthquake shaking under conditions of constant effective vertical stress. In both cases, however, the final result of the shaking and the application of cyclic loading is settlement of the sand.

Although methods of evaluating the two types of settlement have been proposed by Lee and Albaisa (1974) and Silver and Seed (1971), there seems to be no recent work on the prediction of settlements in sands which incorporates findings since about 1975. Considering that even small settlements may sometimes have a significant effect on the performance of structures during earthquakes, it seems desirable to review recent findings and field observations relating to the settlements of sands which may be induced by earthquake shaking.

The object of this paper therefore is to review previous studies, to summarize the available information concerning the settlements of sands during

[1]Research Associate, Tokyo Inst. of Tech., Tokyo, Japan; currently Visiting Scholar, Dept. of Civil Engineering, University of California, Berkeley.

[2]Professor of Civil Engineering, University of California, Berkeley.

earthquakes, and to propose simplified methods of analysis to predict earthquake-induced settlement in both saturated and nonsaturated clean sands.

Review of Previous Studies of Settlements of Saturated Sands

On the basis of laboratory cyclic loading test data, Lee and Albaisa (1974) studied the settlement of sands resulting from the dissipation of excess pore water pressures developed during cyclic loading, and concluded that "the amount of reconsolidation volumetric strain for non-liquefaction conditions increases with increasing grain size of soil, decreasing relative density, and increasing excess pore pressure generated during the undrained cyclic loading, but is almost independent of how this excess pore pressure was generated." Because most tests were stopped before a pore pressure ratio of 100% had developed, no trends were found between reconsolidation volumetric strain after liquefaction and any of the variables mentioned.

Recently, Tatsuoka et al. (1984) studied the volumetric strain after initial liquefaction (pore pressure ratio = 100%) and found that the amount of settlement can be significantly influenced by the maximum shear strain developed in the soil as well as the soil density, but that it is relatively insensitive to effective overburden pressure. Thus the maximum shear strain is an important index of probable settlements after liquefaction since it can vary under such conditions even though there are no significant changes in the maximum pore pressure once a condition of liquefaction has developed.

Volumetric Strain After Liquefaction

Relationships between relative density and volumetric strain after initial liquefaction observed in the studies by Lee and Albaisa (1974), Yoshimi, et al., (1975) and Tatsuoka et al., (1984), are summarized in Fig. 1

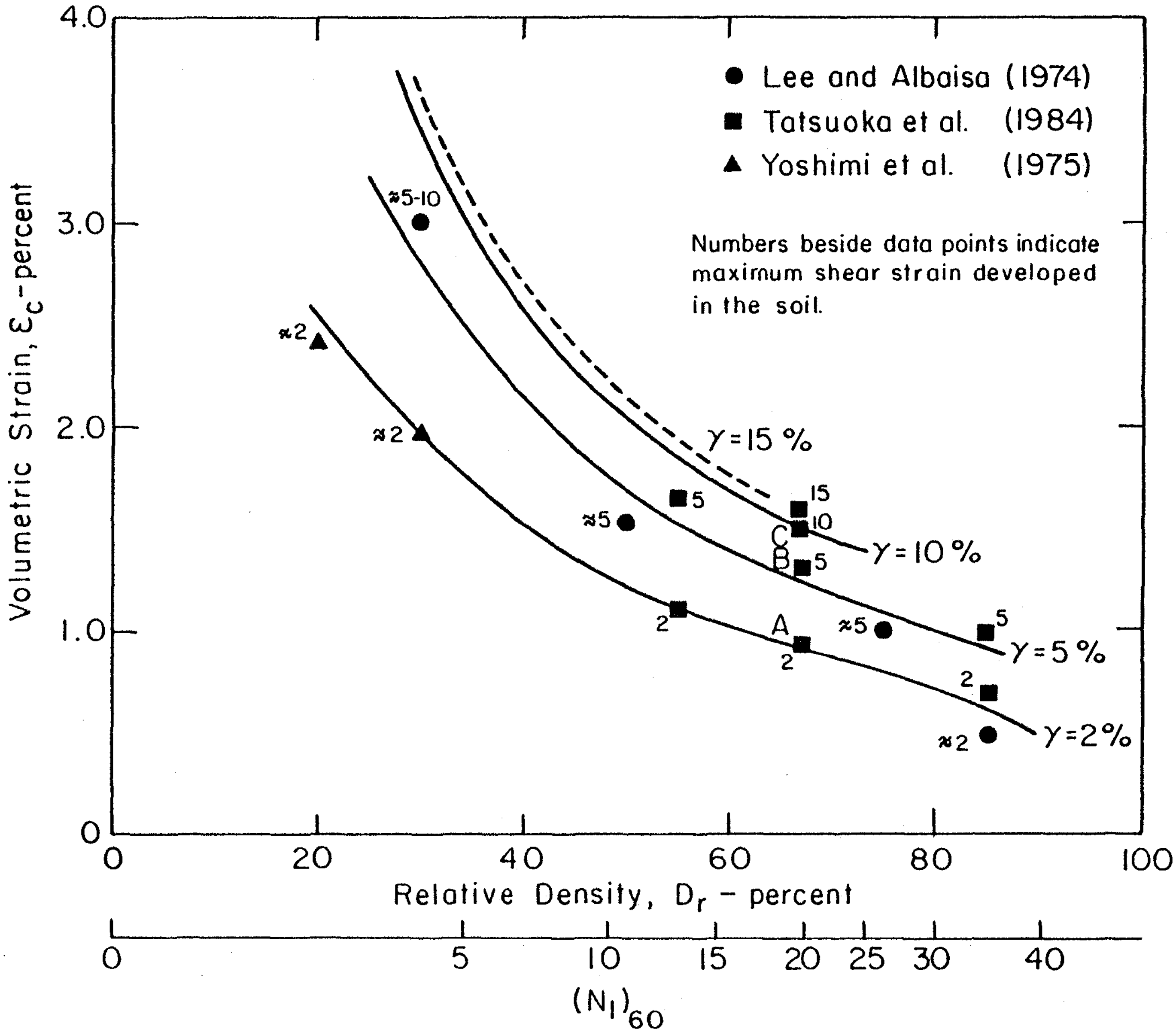


FIG. 1 RELATIONSHIP BETWEEN VOLUMETRIC STRAIN, INDUCED STRAIN AND RELATIVE DENSITY FOR SANDS

in terms of the maximum shear strain occurring in the tests. Although there were no direct measurements of the induced shear strains in the studies by Lee and Albaisa and by Yoshimi et al., a review of the results permits estimates of the strain level likely to have developed in the sands. Also shown in the figure are the best-fit curves representing the data from all three studies. It may be seen that the volumetric strain decreases significantly with increasing relative density and decreasing induced strain in the soil.

The liquefaction resistance of a sand, usually expressed in terms of the stress ratio (τ_{av}/σ_o'), is strongly dependent on such factors as method of sample preparation and stress history effects. However, these factors are likely to become less significant when dealing with the volumetric strain after liquefaction, and this aspect of soil behavior may well be influenced primarily by only the relative density and the maximum shear strain developed in a sand. Thus it is not unreasonable to expect that the relationship shown in Fig. 1 can be used as an approximate basis for estimating the settlement of other saturated sands after liquefaction, provided that the soil density in the field can be estimated with a reasonable degree of accuracy.

The shear strain developed in situ during earthquakes may be estimated from Fig. 2 (after Seed et al., (1984a)) which shows values of the shear strain potential for any combination of cyclic shear stress ratio and normalized SPT N-value for a magnitude 7.5 earthquake. A similar chart was presented by Tokimatsu and Yoshimi (1983) for N-values measured in Japanese practice where the effective energy delivered by the hammer is generally higher than that in U.S. practice. A recent study by Tokimatsu and Yoshimi (1984) showed that the maximum strain potential is reasonably consistent with the limiting strain potentials proposed by Seed (1979) when the difference in energy ratios in SPT determinations in the two countries is taken into account.

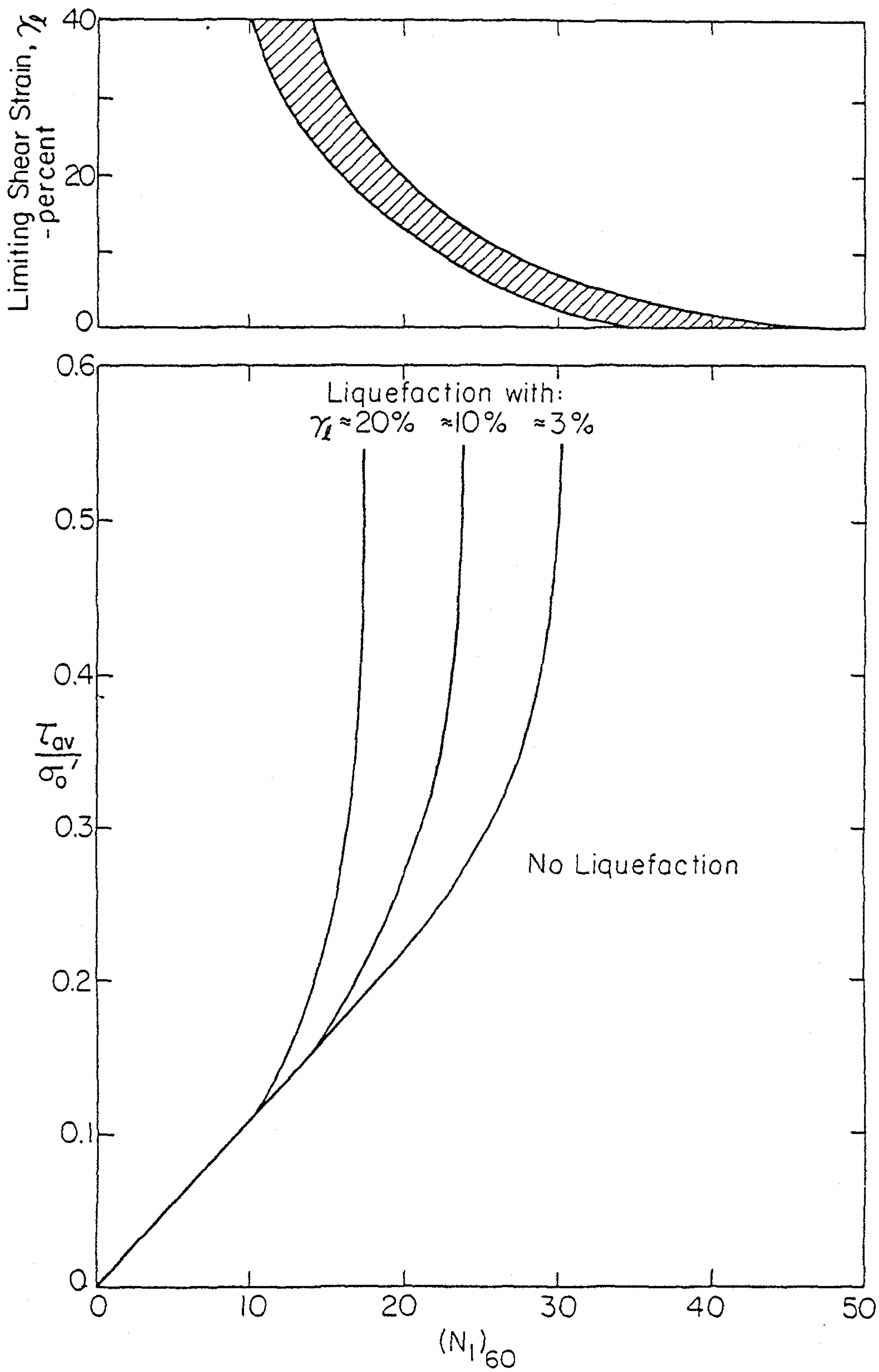


FIG. 2 RELATIONSHIP BETWEEN CYCLIC STRESS RATIO CAUSING LIQUEFACTION, SPT N-VALUE AND LIMITING SHEAR STRAIN (after Seed et al., 1984)

The shear stress ratio in Fig. 2 is given by:

$$\frac{\tau_{av}}{\sigma_o'} = 0.65 \cdot a_{max} \cdot \frac{\sigma_o}{\sigma_o'} \cdot r_d \tag{1}$$

in which τ_{av} = average cyclic shear stress induced by the earthquake shaking, a_{max} = maximum horizontal acceleration at the ground surface, σ_o = total overburden pressure at the depth considered, σ_o' = effective overburden pressure, and r_d = stress reduction factor varying from a value of 1 at the ground surface to a value of about 0.9 at a depth of 30 ft. The normalized SPT N-value (Kovacs et al., (1984); Seed, et al., (1984a)) may be determined by:

$$(N_1)_{60} = C_{ER} \cdot C_N \cdot N \tag{2}$$

in which $(N_1)_{60}$ = SPT N-value normalized to an effective overburden pressure of 1 tsf and to an effective energy delivered to the drill rods equal to 60% of the theoretical free-fall energy, N = measured SPT N-value, C_N = a correction factor in terms of effective stress as shown in Fig. 3, and C_{ER} = a correction factor for the energy developed in the SPT determinations. Typical values of C_{ER} for current practice are summarized in Table 1 (Seed, et al., (1984a)).

The results presented in Figs. 1 and 2 may be combined with the aid of a relationship between relative density and SPT N_1-values. It has been found in Japanese practice (e.g. Tatsuoka, et al., (1978); Tokimatsu and Yoshimi, (1983)) that a good relationship between these parameters is provided by the expression proposed by Meyerhof (1957), viz.:

$$D_r = 21 \sqrt{\frac{N_j}{\sigma_o' + 0.7}} \tag{3}$$

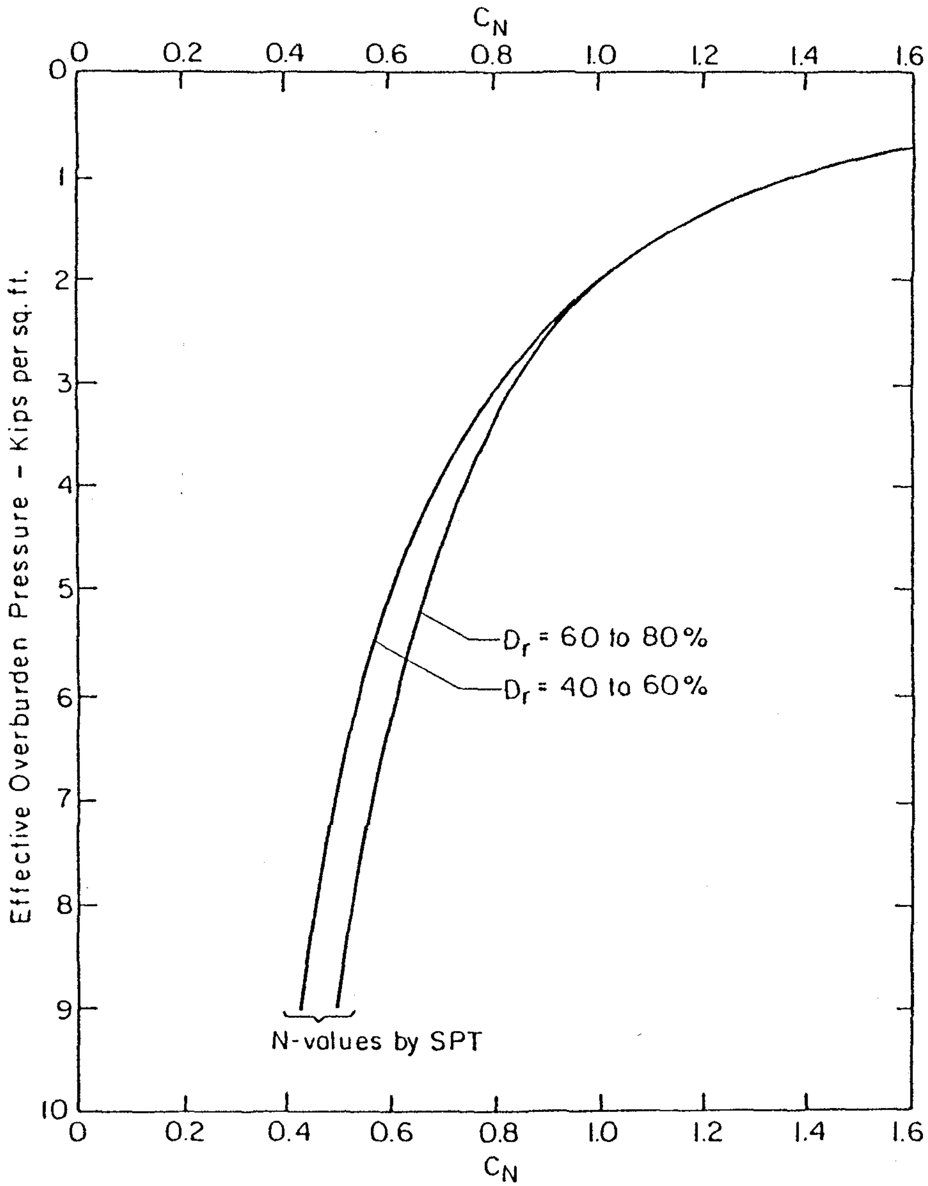


FIG. 3 CURVES FOR DETERMINATION OF C_N

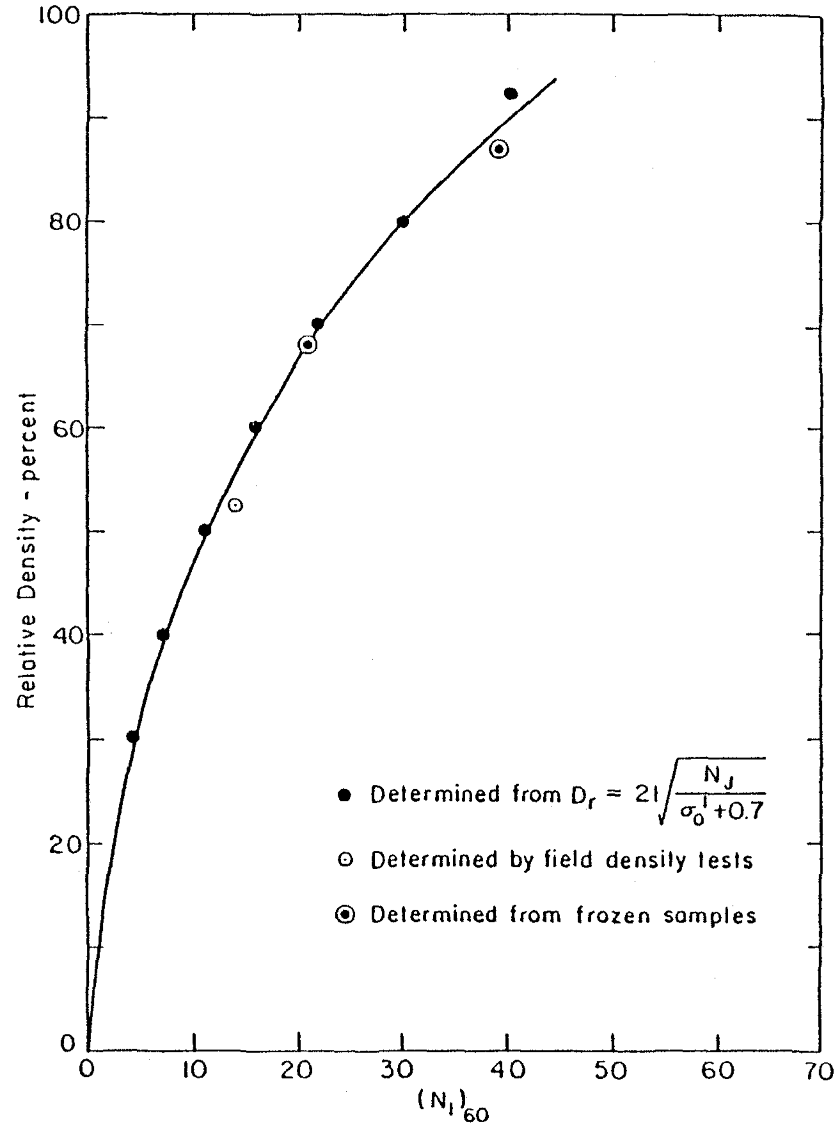


FIG. 4 RELATIONSHIP BETWEEN RELATIVE DENSITY AND $(N_1)_{60}$

Table 1 Rod-Energies in SPT-Practice

Country	Hammer Type	Hammer Release	Estimated Rod Energy (%)	Correction Factor for 60% Rod Energy
I. JAPAN**				
A.	Donut	Free-Fall	78	78/60 = 1.3
* B.	Donut	Rope & Pulley with special throw release	67	67/60 = 1.12
II. USA				
* A.	Safety	Rope & Pulley	60	60/60 = 1.0
B.	Donut	Rope & Pulley	60/1.33 = 45	45/60 = 0.75
III. ARGENTINA				
A.	Donut	Rope & Pulley	45	45/60 = 0.75
IV. EUROPE				
* A.	Donut	Free-Fall	60	60/60 = 1.0
V. CHINA				
* A.	Donut	Free-Fall	60	60/60 = 1.0
B.	Donut	Rope & Pulley	60X 0.825 = 50	50/60 = 0.83

*Prevalent method in this country today.

**Japanese SPT results have additional corrections for borehole diameter and frequency effects.

where N_J = SPT N-value measured in Japanese practice

σ_o' = effective overburden pressure in ksc.

However Japanese practice in the measurement of N-values involves the use of a higher energy ratio than that used in U.S. practice, together with other minor differences (Seed, et al., (1984a)). Thus the authors have chosen to convert the results expressed by Eqn. (3) to corresponding values in terms of N_{60}, where N_{60} is the SPT N-value determined by a method providing 60% of the theoretical free-fall energy to the drill rods as well as other standards of practice as listed in Table 2. Points expressing this relationship are plotted in Fig. 4.

Table 2 Recommended SPT Procedure for Use in Settlement Correlations

A. Borehole: 4 to 5-inch diameter rotary borehole with bentonite drilling mud for borehole stability

B. Drill Bit: Upward deflection of drilling mud (tricone of baffled drag bit)

C. Sampler: O.D. = 2.00 inches
I.D. = 1.38 inches - constant (i.e. no room for lines in barrel)

D. Drill Rods: A or AW for depths less than 50 feet
N or NW for greater depths

E. Energy Delivered to Sampler: 2520 in.-lbs. (60% of theoretical maximum)

F. Blowcount Rate: 30 to 40 blows per minute

G. Penetration Resistance Count: Measures over range of 6 to 18 inches of penetration into the ground

Also shown in Fig. 4 are several points determined by recent studies on natural deposits of sand where the relative density was measured using undisturbed samples obtained by in-situ freezing (Tokimatsu and Yoshimi (1983);

Yoshimi, (1984)) and a data point from an old deposit where the relative density was determined on the basis of field density measurements. It may be seen that all of the results shown are in good agreement and the relationship shown on this figure has therefore been adopted for use in the present study. It should be noted that this relationship is somewhat different from that provided by laboratory studies since it takes into account the effect of ageing on the SPT N-value of sands (Mitchell, (1984)), and is thus likely to be indicative of the relationship which might be expected for natural or older deposits.

The relationship between relative density and $(N_1)_{60}$ shown in Fig. 4 is plotted along the abscissa in Fig. 1, thereby providing an approximate relationship between volumetric strain after liquefaction and SPT N-values expressed in terms of $(N_1)_{60}$.

The volumetric strains for different combinations of $(N_1)_{60}$-values and shear strain can be read off from Fig. 1 and plotted at the corresponding points on Fig. 2, as shown on Fig. 5. For example, the points labelled A, B, and C in Fig. 1 corresponding to $(N_1)_{60}$ = 20 and shear strains of 2, 5 and 10% would correspond to volumetric strains of 0.9, 1.2 and 1.5% and would be plotted as points A', B' and C' in Fig. 5. It is now possible, based on the values of volumetric strains after liquefaction shown on Fig. 5, to draw equi-volumetric shear strain lines on the stress ratio vs SPT $(N_1)_{60}$ chart as shown by the solid lines in Fig. 6. It should be noted that the resulting volumetric strains after liquefaction may be as high as 2 to 3% for loose to medium dense sands and even higher for very loose sands.

Volumetric Strain After Incomplete Liquefaction

Even though liquefaction may not occur, some pore pressure may be

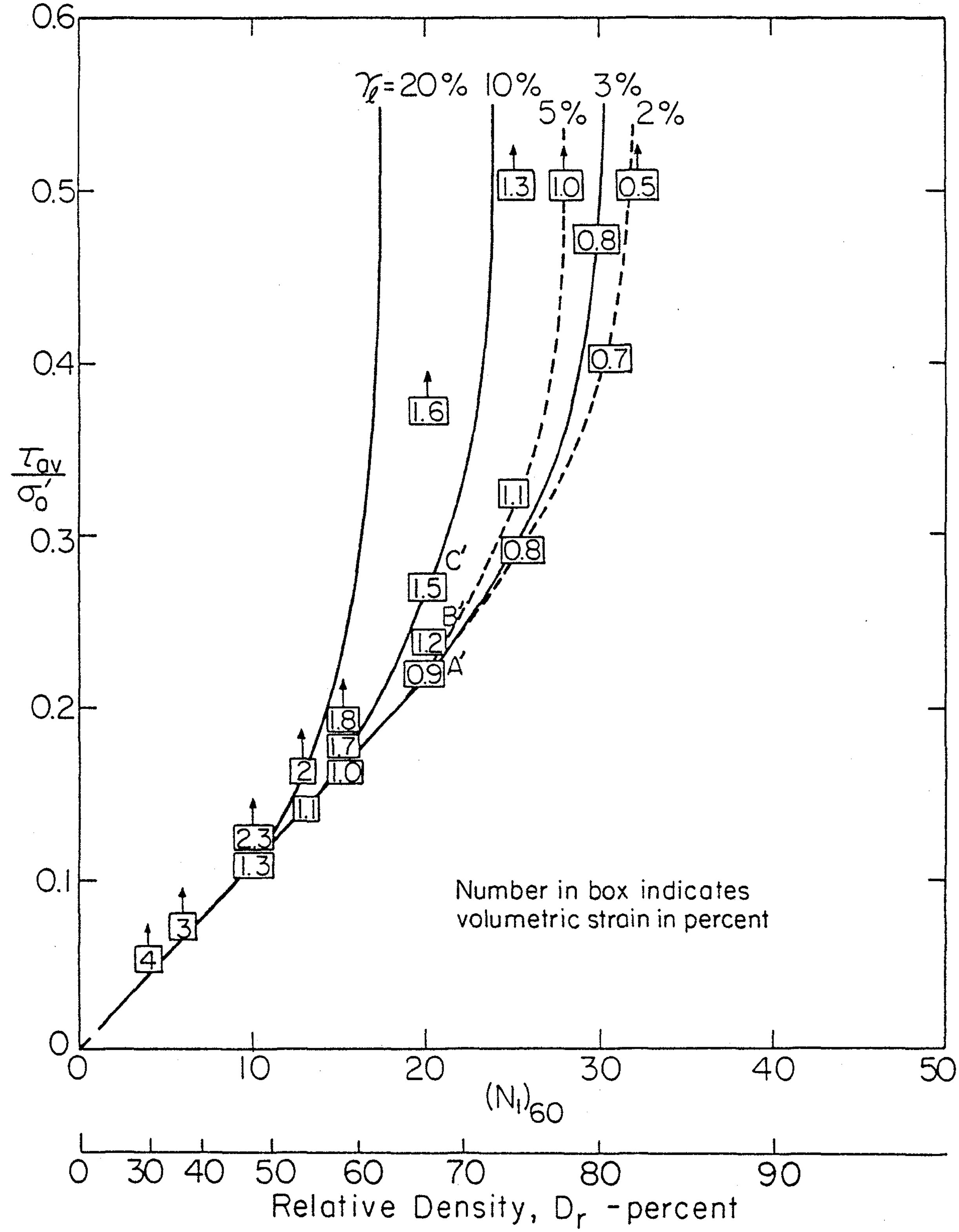


FIG. 5 RELATIONSHIP BETWEEN CYCLIC STRESS RATIO, VOLUMETRIC STRAIN AND $(N_1)_{60}$

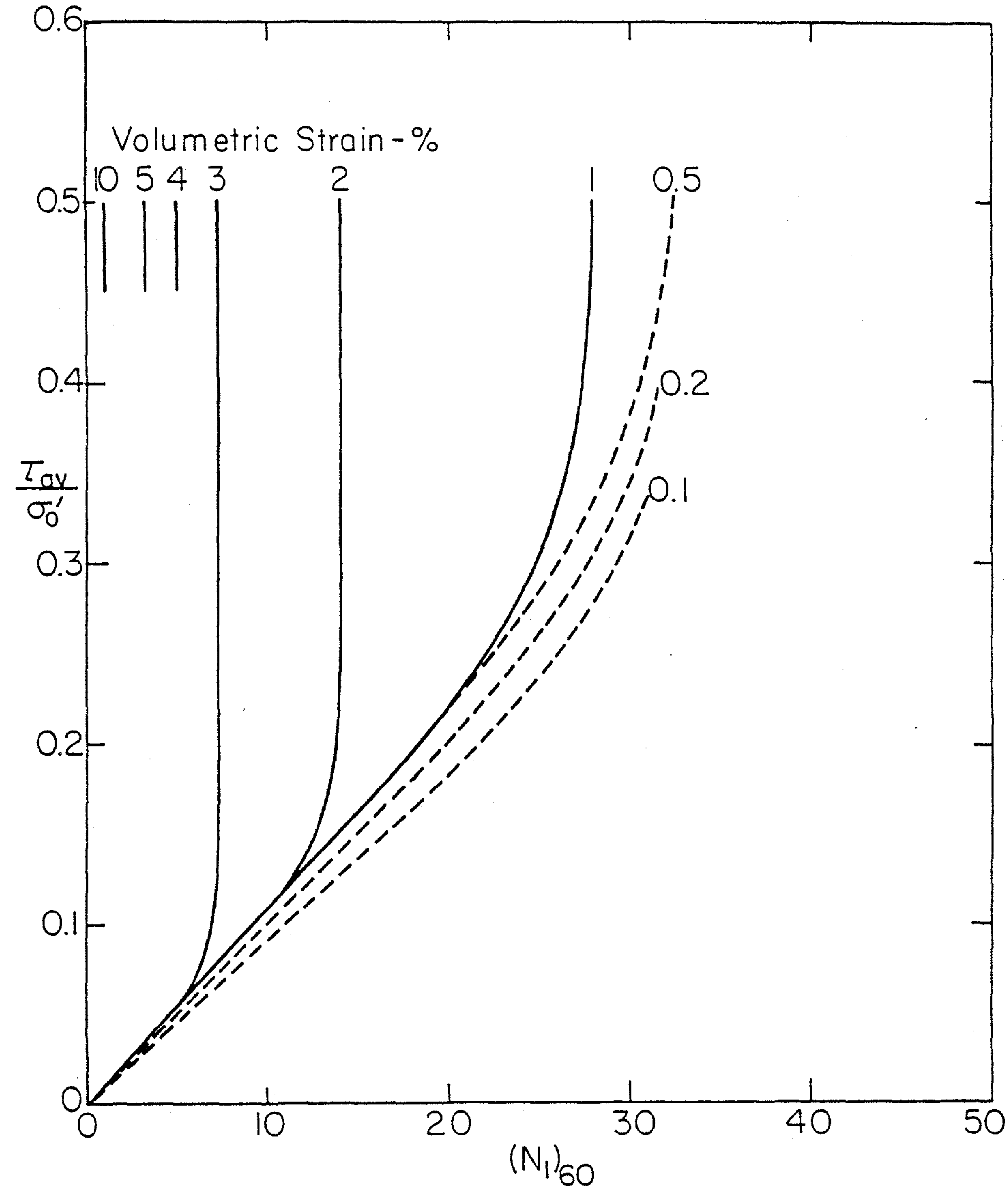


FIG. 6 PROPOSED RELATIONSHIP BETWEEN CYCLIC STRESS RATIO, $(N_1)_{60}$ AND VOLUMETRIC STRAIN FOR SATURATED CLEAN SANDS

generated in sand deposits by earthquake shaking and the dissipation of this pore pressure may result in small amounts of settlement. This condition corresponds to the zone below the boundary line for liquefaction shown in Fig. 2 and below the solid line marked volumetric strain = 0.5% in Fig. 6. The pore pressure generated under such conditions may be expressed in terms of the normalized stress ratio; that is the ratio of the actual shear stress ratio to the stress ratio just causing liquefaction. The relationship between the pore pressure ratio and the normalized stress ratio generally falls within the shaded area in Fig. 7 and for most sands may be represented by the broken line shown in the figure (Tokimatsu and Yoshimi, (1983)).

Lee and Albaisa (1974) plotted volumetric strain as a function of induced pore pressure ratio as shown in Fig. 8 and concluded that, for pore pressure ratios less than about 0.6, the relationship between volumetric strain and peak pore pressure ratio could be represented for practical purposes by the dashed line shown in the figure for sands with relative densities in the range of 30 to 80% and regardless of the confining pressure. Thus by combining the average results shown in Figs. 7 and 8, Fig. 9 can readily be prepared to determine a relationship between volumetric strain and normalized stress ratio. Note that even for a condition where the stress ratio is about 0.8 times that required to cause liquefaction (i.e. factor of safety against liquefaction is about 1.25) the resulting volumetric strain is only about 0.1%. The relationship shown in Fig. 9 is also drawn in Fig. 6 with broken lines.

It may be noted that if the normalized stress ratio is less than 0.7, the induced pore pressure ratio is likely to be less than 0.1 according to Fig. 7, and hence the effect of pore pressure generation on settlement is likely to be insignificant for most structures.

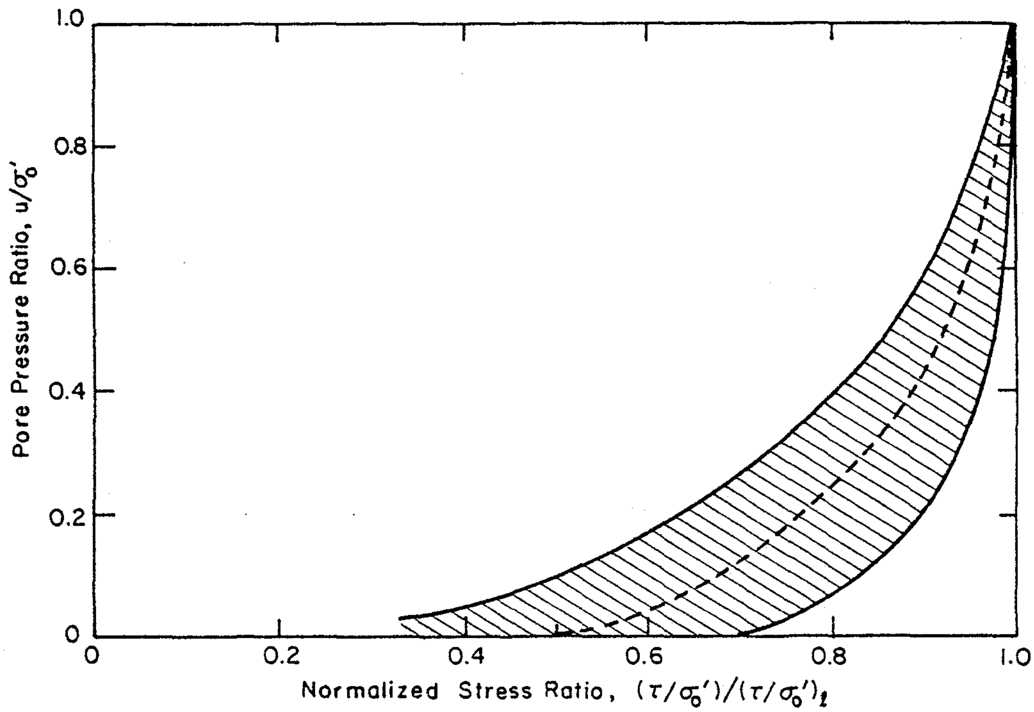


FIG. 7 RELATIONSHIP BETWEEN INDUCED PORE PRESSURE RATIO AND NORMALIZED STRESS RATIO FOR CLEAN SANDS

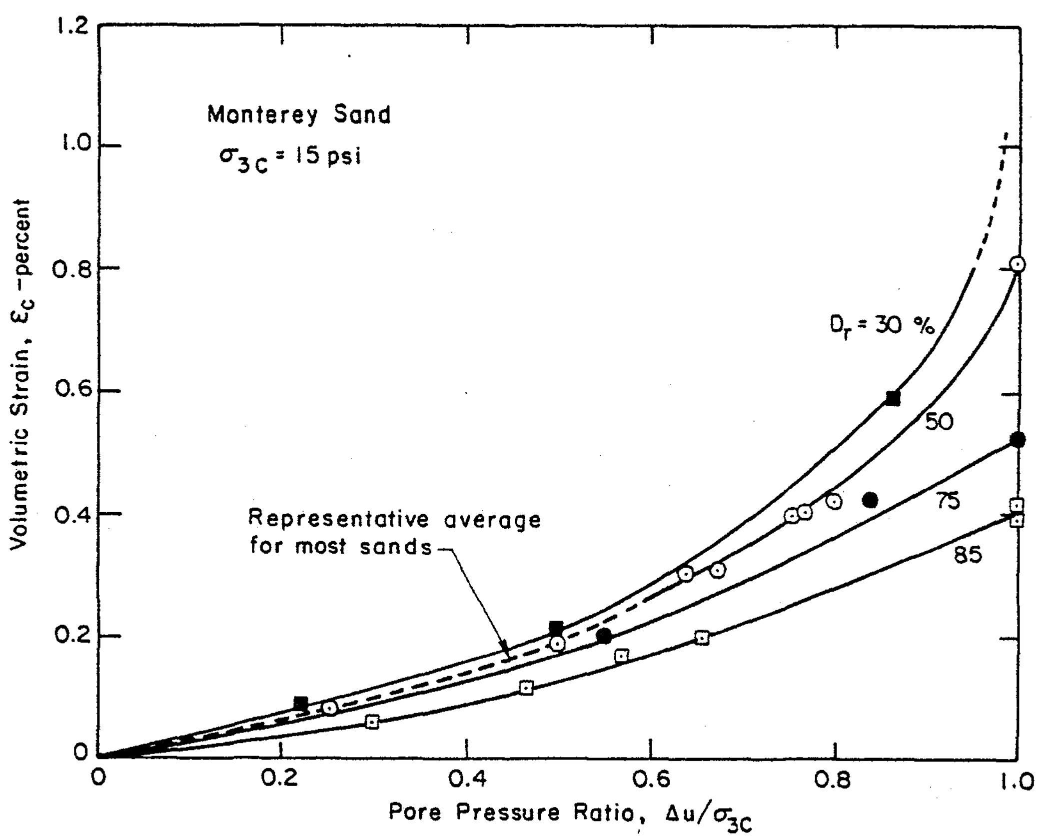


FIG. 8 RELATIONSHIP BETWEEN VOLUMETRIC STRAIN AND INDUCED PORE PRESSURE RATIO (after Lee and Albaisa, 1974)

Effects of Earthquake Magnitude on Settlement in Saturated Sands

The chart in Fig. 6 can be extended to other magnitude events by noting that the main difference between different magnitude earthquakes is the difference in number of cycles of stress they produce (e.g. Seed, et al., (1983)). The relative values of stress ratio required to cause liquefaction for earthquakes of different magnitudes to the stress ratio required to cause liquefaction for a M = 7.5 event are summarized in Table 3, together with the corresponding numbers of cycles induced by the earthquakes. Thus by multiplying the values of the ordinate for each eqi-volumetric strain line in Fig. 6 by the scaling factors shown in Column 3 of Table 3, volumetric strain charts can be obtained for earthquakes with different magnitudes. Alternatively Fig. 6 can be used for any magnitude event simply by modifying the values of the cyclic stress ratios for those earthquakes into equivalent values for M = 7.5 earthquakes using the relationship

$$\left(\frac{\tau_{av}}{\sigma_o'}\right)_{M=7.5} = \left(\frac{\tau_{av}}{\sigma_o'}\right)_{M=M} \times \frac{1}{r_m} \qquad (3)$$

where r_m has the values shown in Column 3 of Table 3.

Table 3 Scaling Factors for Effect of Earthquake Magnitude on Effective Cyclic Stress Ratio

Earthquake Magnitude, M (1)	Number of Representative Cycles at 0.65 τ_{max} (2)	Scaling Factor for Stress Ratio, r_m (3)
8-1/2	26	0.89
7-1/2	15	1.0
6-3/4	10	1.13
6	5	1.32
5-1/4	2-3	1.5

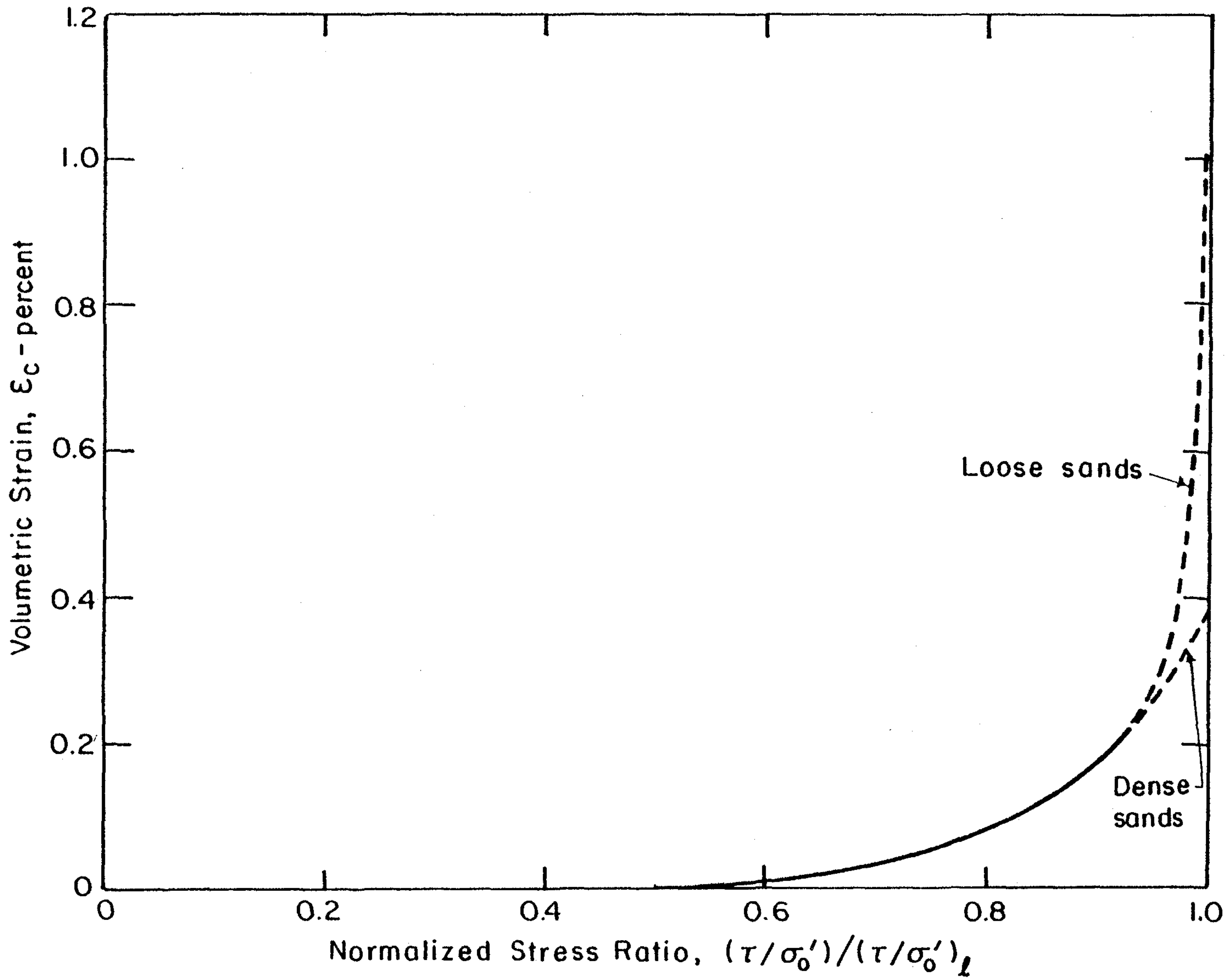


FIG. 9 RELATIONSHIP BETWEEN VOLUMETRIC STRAIN AND NORMALIZED PORE PRESSURE RATIO FOR SATURATED CLEAN SANDS

Observed Settlements in Saturated Sands

In order to compare the values of volumetric strain shown on the chart in Fig. 6 with field behavior, information concerning volumetric strains for several field cases of seismically induced settlement of saturated sands are summarized in Table 4, and the resulting volumetric strains are plotted on the chart in Fig. 10. Although the number of field cases for which data is available is quite limited, the field evidence is generally consistent with the lines drawn in the figure.

Typical examples of the computation of settlements for two cases reported by Ohsaki (1970) where settlements occurred in saturated sand during the Tokachi-oki earthquake of 1968 are shown in Table 5. The sites are designated P6 and P1 respectively. For site P6 the sand deposit was extremely loose to a depth of about 20 ft and the observed maximum settlement was about 20 inches. Based on values of the volumetric strain in different depth zones taken from the chart in Fig. 6, the computed settlement was 15.5 inches as shown in the upper part of Table 4. For site P1 the sand was medium dense and the observed settlement was only about 0.6 inch. The computed value, determined as shown in the lower part of Table 4, was about 0.7 inch. In both cases the computed settlements are in good agreement with the reported values. This good agreement between the measured and predicted values indicates the possibility of using the chart as a basis for estimating probable settlements of saturated sands due to earthquake shaking.

Review of Previous Studies on Dry Sands

Silver and Seed (1971) have shown that the settlement of dry sands due to cyclic loading is a function of: (1) the relative density of the soil; (2) the magnitude of the cyclic shear strain; and (3) the number of strain cycles. It

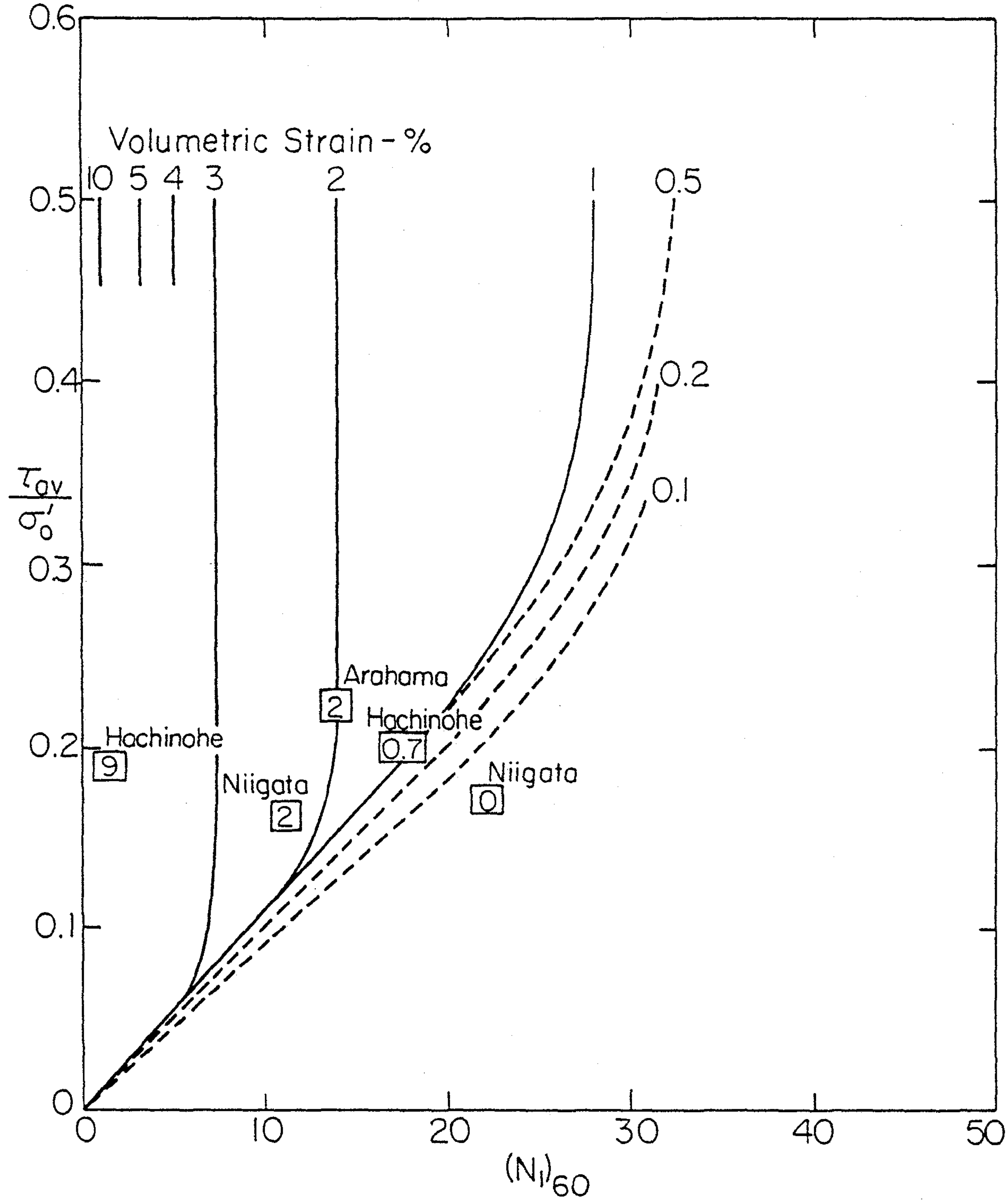


FIG. 10 COMPARISON OF PROPOSED CHART FOR DETERMINATION OF VOLUMETRIC STRAIN WITH FIELD PERFORMANCE OF SATURATED SANDS

Table 4 Field Observations of Earthquake-Induced Settlements in Saturated Sands

Earthquake	Year	Magnitude	Maximum Acceleration	Thickness of Layer Causing Major Settlement (ft)	Observed Settlement (in)	Volumetric Strain (%)	Average Stress Ratio	Average SPT $(N_1)_{60}$	Fines Content (%)	Reference
Tokachioki	1968	7.9	0.2	16	15-20	9	0.19	1.4	5	Ohsaki (1970)
"	"	7.9	0.23	7	0.5-0.7	0.7	0.2	17.5	5	" "
Niigata	1964	7.5	0.16	30	8	2	0.16	11	2	Building Research Institute (1965)
"	"	7.5	0.18	30	0	0	0.17	22	2	
Miyagiken Oki	1978	7.4	0.2	30	8	2	0.22	14	0	Tohno et al.(1981)

Table 5 Computation of Settlement for Saturated Sand--Comparison of Proposed Method with Field Observation made by Ohsaki (1970)

P-6

Water Table 4 ft
Estimated Maximum Acceleration ≈ 0.20

Layer #	Thickness (ft)	N	C_{ER}	σ_o	σ_o'	C_N	$(N_1)_{60}$	$(\tau/\sigma_o')_{ave}$	Volumetric Strain (%)	Settlement (in)
1	4	1	0.82*	240	240					
2	3.3	0.5	0.82*	678	575	1.7	0.7	0.155	10	4
3	3.3	0.5	0.82*	1074	764	1.57	0.6	0.185	10	4
4	3.3	0.5	1.09	1470	954	1.44	0.8	0.20	10	4
5	3.3	2	1.09	1866	1144	1.34	2.9	0.21	5.5	2.2
6	3.3	5	1.09	2262	1334	1.24	6.8	0.215	3.2	1.3
7	3.3	23	1.21	2658	1523	1.16	32	0.22	0	
8	3.3	33	1.21	3054	1713	1.09	44	0.225	0	
9	3.3	28	1.21	3450	1903	1.03	35	0.225	0	
10	3.3	33	1.21	3846	2093	0.97	39	0.225	0	

Estimated settlement = 15.5 in
Actual settlement ≈ 20 in (max)

P-1

Water Table 3.3 ft
Estimated Maximum Acceleration ≈ 0.23

Layer #	Thickness (ft)	N	C_{ER}	σ_o	σ_o'	C_N	$(N_1)_{60}$	$(\tau/\sigma_o')_{ave}$	Volumetric Strain (%)	Settlement (in)
1	3.3	12	0.82*	198	198					
2	3.3	12	0.82*	594	490	1.8	18	0.185	0.3	0.1
3	3.3	13	0.82*	990	681	1.63	17	0.22	1.5	0.6
4	3.3	20	1.21	1386	870	1.50	36	0.24	0	
5	3.3	36	1.21	1782	1060	1.38	60	0.25	0	

Estimated settlement = 0.7 in
Actual settlement ≈ 0.5 ~ 0.7 in

*Corrected by 0.75.

was also found that for a given density and number of cycles, settlement is not significantly affected by the value of the vertical stress and depends only on the shear strain amplitude in the soil. Based on these results, Seed and Silver (1972) suggested a procedure for estimating the probable settlement of dry sand, involving a response analysis for the deposit to determine the induced shear strains developed at different depths in the soil. The analysis was modified by Pyke, et al. (1975) to allow for multidirectional shaking effects which were found to have an important influence on the magnitude of settlements.

The method outlined below is a simplified version of the Seed and Silver method of analysis and offers the advantage that it can be performed without the need for a response analysis for the deposit.

Shear Strain Developed in the Ground During Earthquakes

As stated above, the primary factor controlling settlements in dry sands is the cyclic shear strain induced in the soil at various depths. Values of this strain may be estimated as follows.

At any given depth in a soil deposit, the effective shear strain, γ_{eff} induced by earthquake shaking may be estimated from the relationship:

$$\gamma_{eff} = \frac{\tau_{av}}{G_{eff}} = \frac{\tau_{av}}{G_{max} \cdot (G_{eff}/G_{max})} \tag{4}$$

in which G_{max} = shear modulus at low strain level, G_{eff} = effective shear modulus at induced strain level and τ_{av} = average cyclic shear stress at the corresponding depth. τ_{av} may be computed from the relationship (Seed and Idriss, (1971)):

$$\tau_{av} = 0.65 \cdot \frac{a_{max}}{g} \cdot \sigma_o \cdot r_d \tag{5}$$

Substituting Eq. (5) into Eq. (4) and rearranging the terms leads to:

$$\gamma_{eff} \left(\frac{G_{eff}}{G_{max}} \right) = \frac{0.65 \cdot a_{max} \cdot \sigma_o \cdot r_d}{G_{max}} \tag{6}$$

The right hand side of this equation can readily be evaluated for any given depth, since G_{max} may be determined from the relationship (Seed and Idriss, (1970)):

$$G_{max} = 1000 \cdot (K_2)_{max} \cdot (\sigma_m')^{1/2} \text{ in psf units}$$

where $(K_2)_{max} \simeq 20 (N_1)_{60}{}^{1/3}$.

The latter equation is based on the correlation proposed by Ohta and Goto (1976) as a result of numerous field shear wave measurements in Japan and subsequently modified to the above form by Seed, et al., (1984b).

Having thus determined a value for the product $\gamma_{eff} \cdot (G_{eff}/G_{max})$, a value for γ_{eff} can be determined as follows. A typical representative relationship between the ratio G_{eff}/G_{max} and shear strain for sands, based on the work of many investigations is shown in Fig. 11(a). Most investigators find relationships lying within the band shown in this figure (Seed, et al., (1984b)). In detail the relationship is also dependent on the confining pressure as shown by Hardin and Drnevich (1971), Shibata and Soelarno (1975) and Iwasaki, et al., (1978) and is perhaps best represented in detail by the family of curves proposed by Iwasaki, et al., shown in Fig. 11(b). From these relationships, values of the product of $(G_{eff}/G_{max}) \cdot \gamma_{eff}$ can readily be computed and plotted against the effective shear strain, γ_{eff}, as shown in Fig. 12.

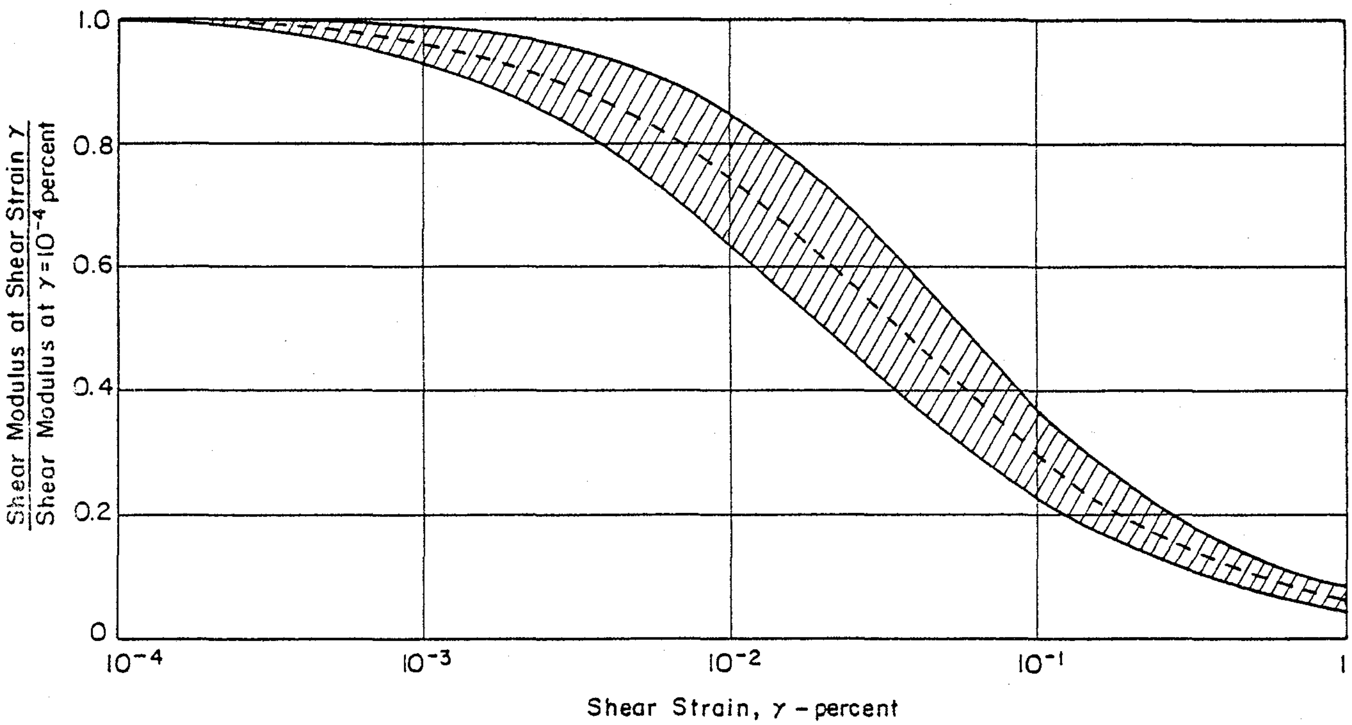


FIG. 11(a) RELATIONSHIP BETWEEN SHEAR MODULUS AND STRAIN FOR SANDS (after Seed et al., 1984)

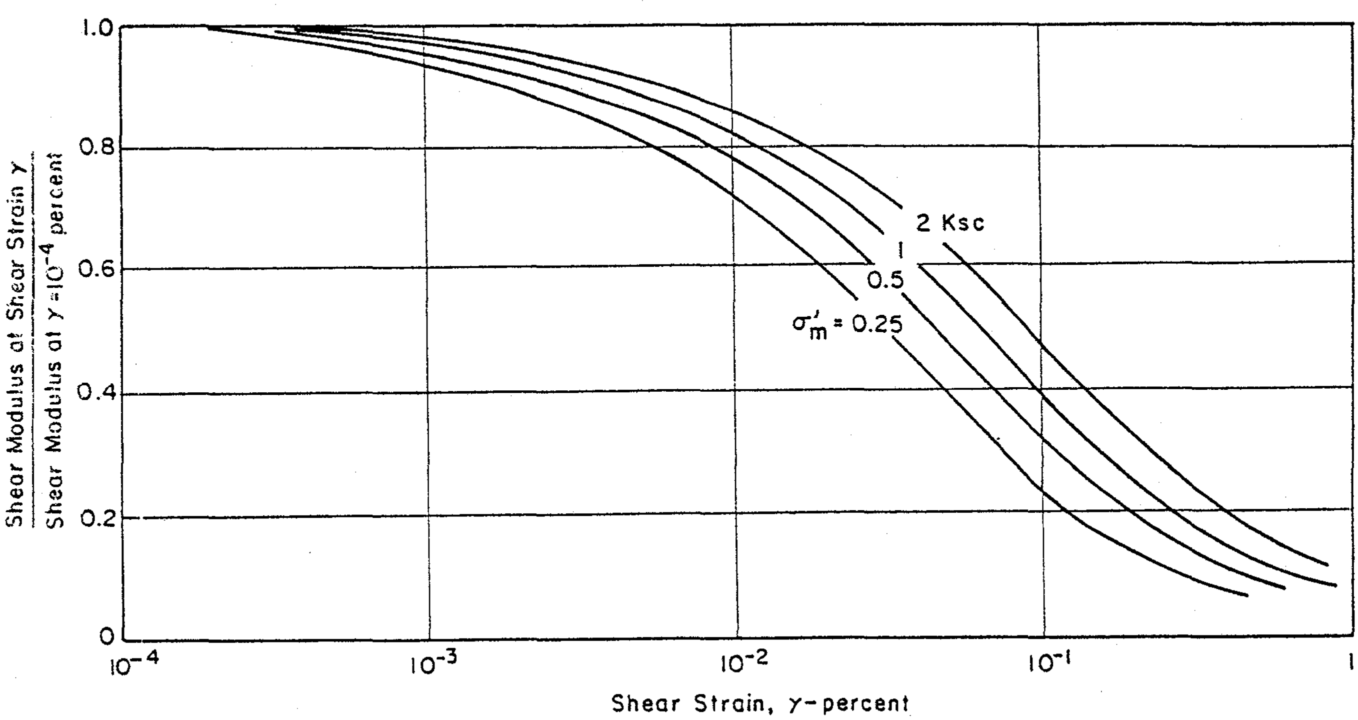


FIG. 11(b) RELATIONSHIP BETWEEN SHEAR MODULUS AND STRAIN FOR SANDS (after Iwasaki et al., 1978)

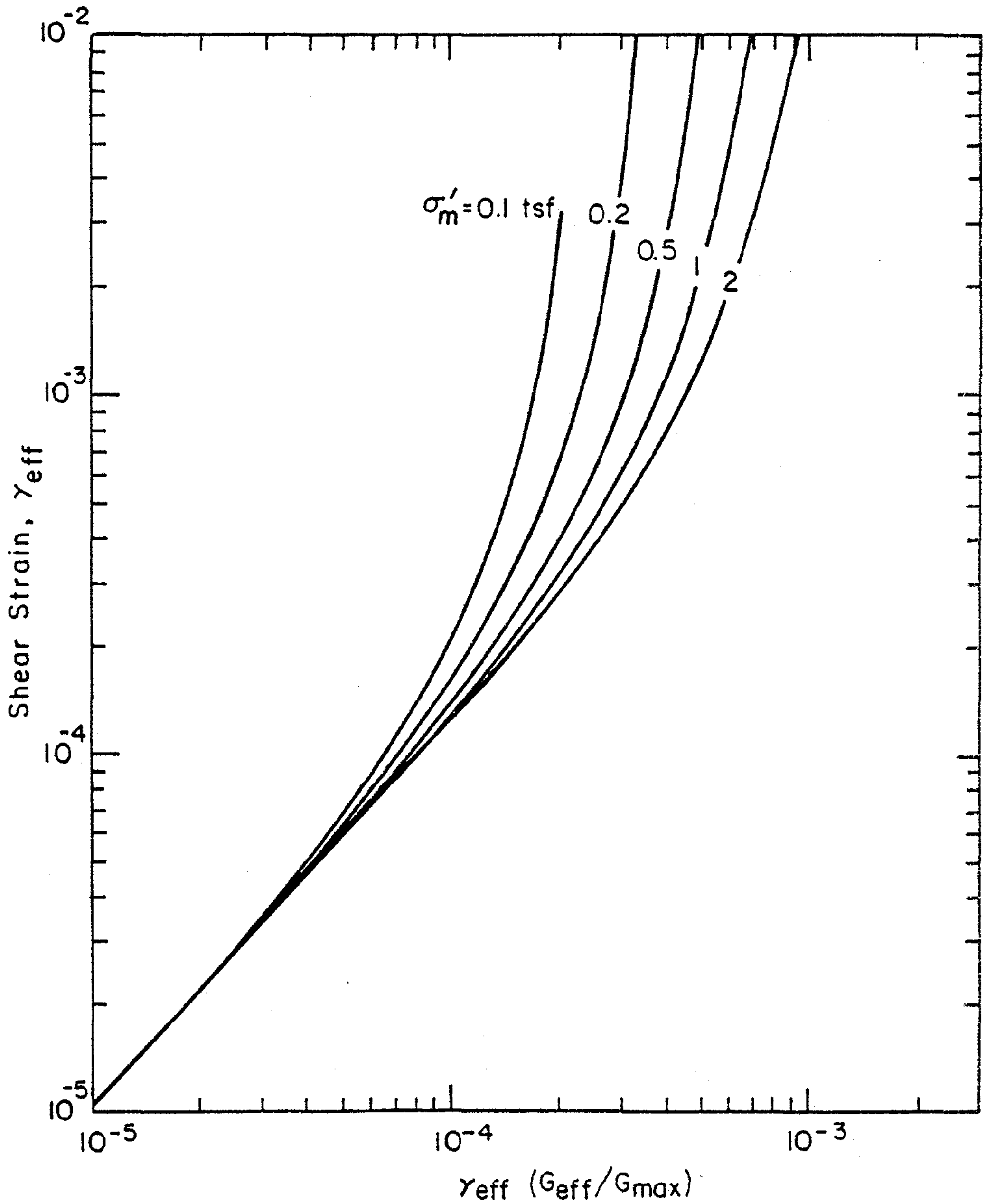


FIG. 12 PLOT FOR DETERMINATION OF INDUCED STRAIN IN SAND DEPOSITS

Thus since the value of the product $(G_{eff}/G_{max}) \cdot \gamma_{eff}$ can be determined for a layer at any depth by means of Eqn. (6), the corresponding value of γ_{eff} can readily be read off from the curves presented in Fig. 12. This procedure is not so accurate as performing a dynamic response analysis but it is probably accurate enough for most settlement estimates in practice.

Volumetric Strain vs. Shear Strain for Dry Sands

Silver and Seed (1971) presented relationships between volumetric strain and shear strain for sands at different relative densities from which the relations after 15 cycles are summarized in Fig. 13. Combining the relationships presented in Figs. 13 and 4, leads to the relationships between volumetric strain and shear strain for sands with different SPT N_1-values as shown in Fig. 14.

The relationships shown in Figs. 13 and 14 are applicable only for cases involving 15 equivalent uniform strain cycles which is typically representative of a magnitude 7.5 earthquake. However, the results can be extended to different magnitude events by a procedure similar to that adopted for saturated sands (e.g., Seed, et al., (1983)). The number of cycles representative of different magnitude events is again tabulated in Table 6.

Table 6 Influence of Earthquake Magnitude on Volumetric Strain Ratio for Dry Sands

Earthquake Magnitude (1)	Number of Representative Cycles at 0.65 τ_{max} (2)	Volumetric Strain Ratio $\varepsilon_{C,N}/\varepsilon_{C,N=15}$ (3)
8-1/2	26	1.25
7-1/2	15	1.
6-3/4	10	0.85
6	5	0.6
5-1/4	2-3	0.4

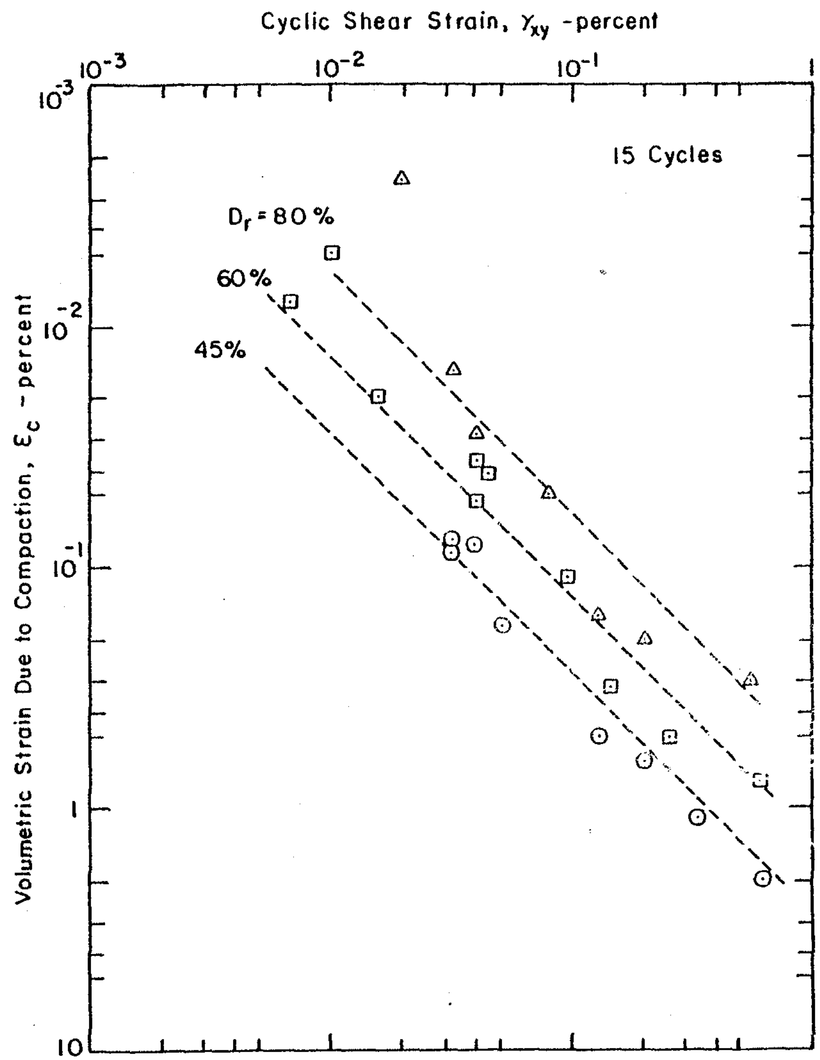


FIG. 13 RELATIONSHIP BETWEEN VOLUMETRIC STRAIN AND SHEAR STRAIN FOR DRY SANDS (after Silver and Seed, 1971)

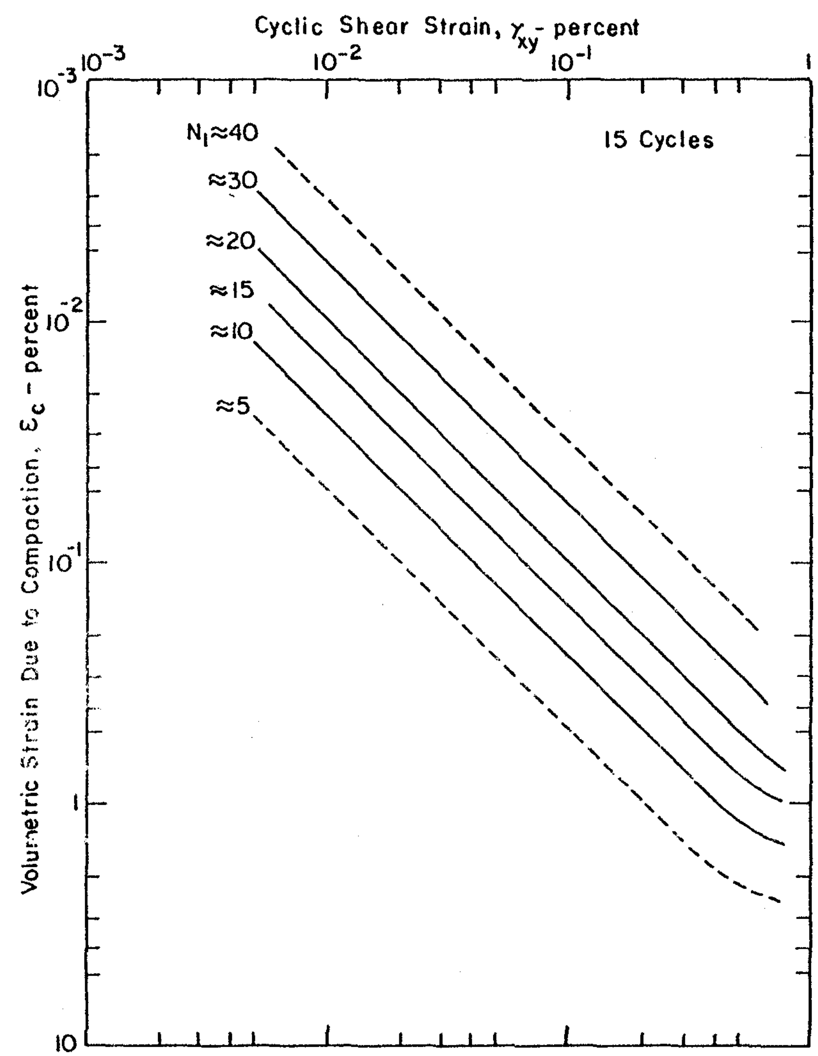


FIG. 14 RELATIONSHIP BETWEEN VOLUMETRIC STRAIN, SHEAR STRAIN AND PENETRATION RESISTANCE FOR DRY SANDS

A review of previous studies (e.g., Silver and Seed, (1971)) shows that the volumetric strain ratios for different numbers of cycles normalized to that for 15 cycles generally falls within the shaded zone shown in Fig. 15 and may be represented by the average line shown in the figure. Thus the ratio of values of volumetric strain in any number of cycles to that for 15 cycles can be readily determined from Fig. 15, and values are listed in the third column of Table 6. By multiplying the volumetric strain from Fig. 14 by the factor shown in Column 3 of Table 6, the volumetric strain can be determined for earthquakes with different magnitudes. It should be noted however that the correction factors are different from those listed in Table 3, since the correction is made here for volumetric strain rather than shear stress ratio.

Finally it is necessary to note that the relations shown in Fig. 14 are based on unidirectional simple shear conditions whereas under actual earthquake loading conditions, soils are subjected to multidirectional shaking. Tests by Pyke, et al., (1975) using multidirectional shear as well as unidirectional shear led to the conclusion that "the settlements caused by combined horizontal motions are about equal to the sum of the settlements caused by the components acting alone." This means that the volumetric strain estimated from Fig. 14 should be doubled to take multidirectional shaking effects into account.

Computation of Settlements in Dry Sand During the San Fernando Earthquake

Seed and Silver (1972) computed the settlement in a 50-ft thick deposit of sand with a relative density of 45% subjected to a maximum surface acceleration of 0.45g as shown in Fig. 16 and concluded that the computed settlement of 2.5 in. was in fairly good agreement with settlements observed during the San Fernando earthquake of 1971. The same soil profile has been

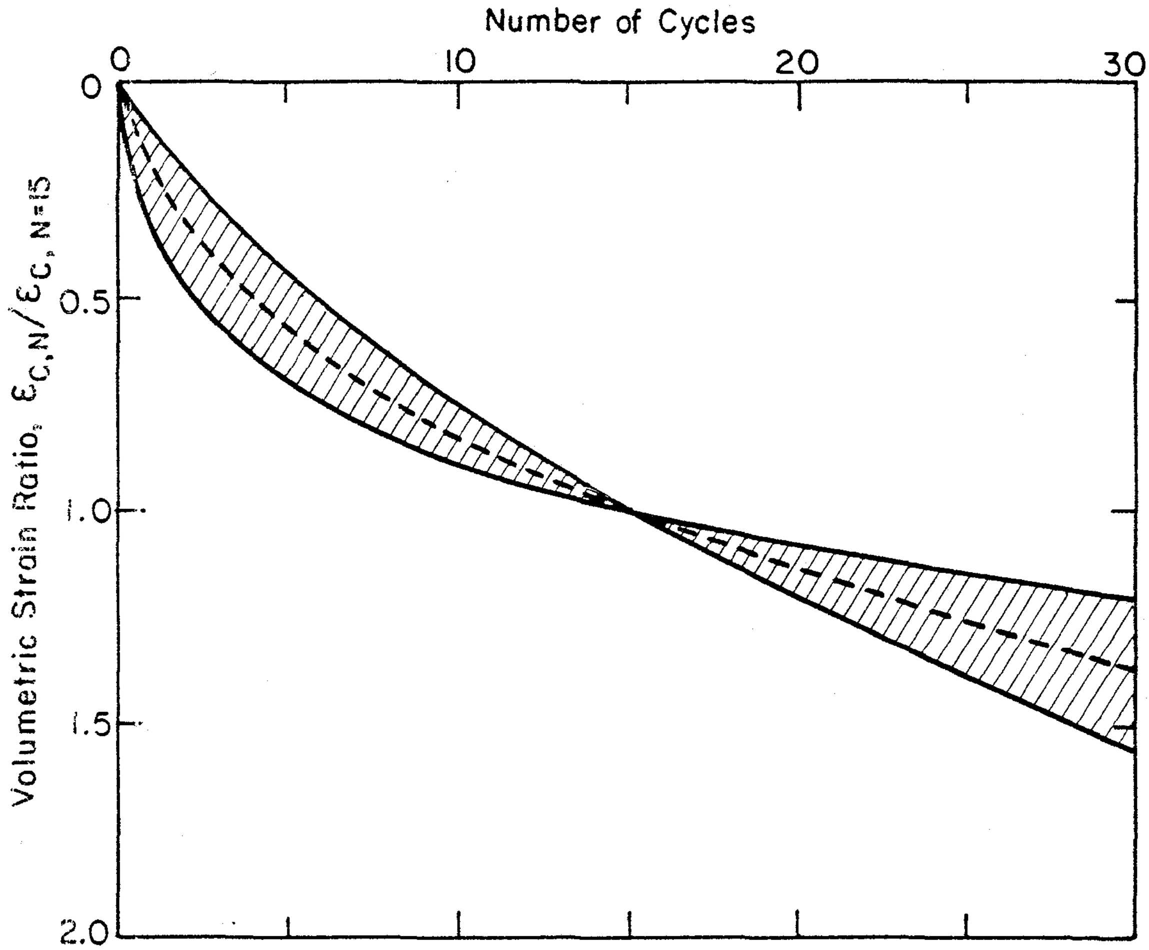


FIG. 15 RELATIONSHIP BETWEEN VOLUMETRIC STRAIN RATIO AND NUMBER OF CYCLES FOR DRY SANDS

evaluated using the simplified method described above. The results of the analyses are shown in Table 7 and the results are compared with those by Seed and Silver (1972) in Fig. 16. It may be noted that the strain distribution determined by the approximate method is in good accord with the values computed by Seed and Silver and that the estimated settlement of about 3 in. is reasonably consistent with field observations.

Conclusions

Simplified methods of analysis have been proposed for estimating probable settlements of either saturated or unsaturated sand deposits subjected to earthquake shaking. Based on a review of previous studies, it appears that the primary factors controlling earthquake-induced settlement are the cyclic stress ratio for saturated sands with pore pressure generation and the cyclic shear strain for dry or partially saturated sands, together with the N-value for the sand and the magnitude of this earthquake.

It should be recognized that, even under static loading conditions, the error associated with the estimation of settlements in sands is on the order of ±25 to 50%. It is therefore reasonable to expect less accuracy in predicting settlements for the more complicated conditions associated with earthquake loading. However, comparison of the numerical results with several case histories indicates that the methods presented herein can be used in many cases as a first approximation for evaluating the volume changes and settlements of sands due to earthquake shaking. In the application of the methods, it is of course essential to check that the final results are reasonable in the light of available experience.

Acknowledgment

The studies described in the preceding pages were sponsored by the National Science Foundation under Research Grant No. CEE-8110734 and the Japan Society for the Promotion of Science. The support of these organizations is gratefully acknowledged.

Table 7 Computation of Settlement for Deposit of Dry Sand

Layer #	Thickness (ft)	$\sigma_o = \sigma_o'$ (psf)	D_r (%)	N_1	G_{max} *3) (ksf)	$\gamma_{eff} (\frac{G_{eff}}{G_{max}})$	γ_{eff}	$\varepsilon_{C,M=7.5}$ (%)	$\varepsilon_{C,M=6.6}$ *1) (%)	$2\varepsilon_{C,M=6.6}$ *2) (%)	Settlement (in)
1	5	240	45	9	520	1.3×10^{-4}	5×10^{-4}	0.14	0.11	0.22	0.13
2	5	715	45	9	900	2.3	8	0.23	0.18	0.36	0.22
3	10	1425	45	9	1270	3.2	12	0.35	0.28	0.56	0.67
4	10	2375	45	9	1630	4.0	14	0.40	0.32	0.64	0.77
5	10	3325	45	9	1930	4.5	15	0.45	0.36	0.72	0.86
6	10	4275	45	9	2190	4.6	13	0.38	0.30	0.60	0.72

3.37 in

*1) $\varepsilon_{C,M=6.6}/\varepsilon_{C,M=7.5} = 0.80$

*2) Multi-directional effect

*3) $G_{max} = K_2 \cdot 1000\ (\sigma_m')^{1/2} \simeq 20\ N_1^{1/3}\ (\sigma_m')^{1/2} \times 1000$

*4) $M = 6.6,\ a_{max} = 0.45$

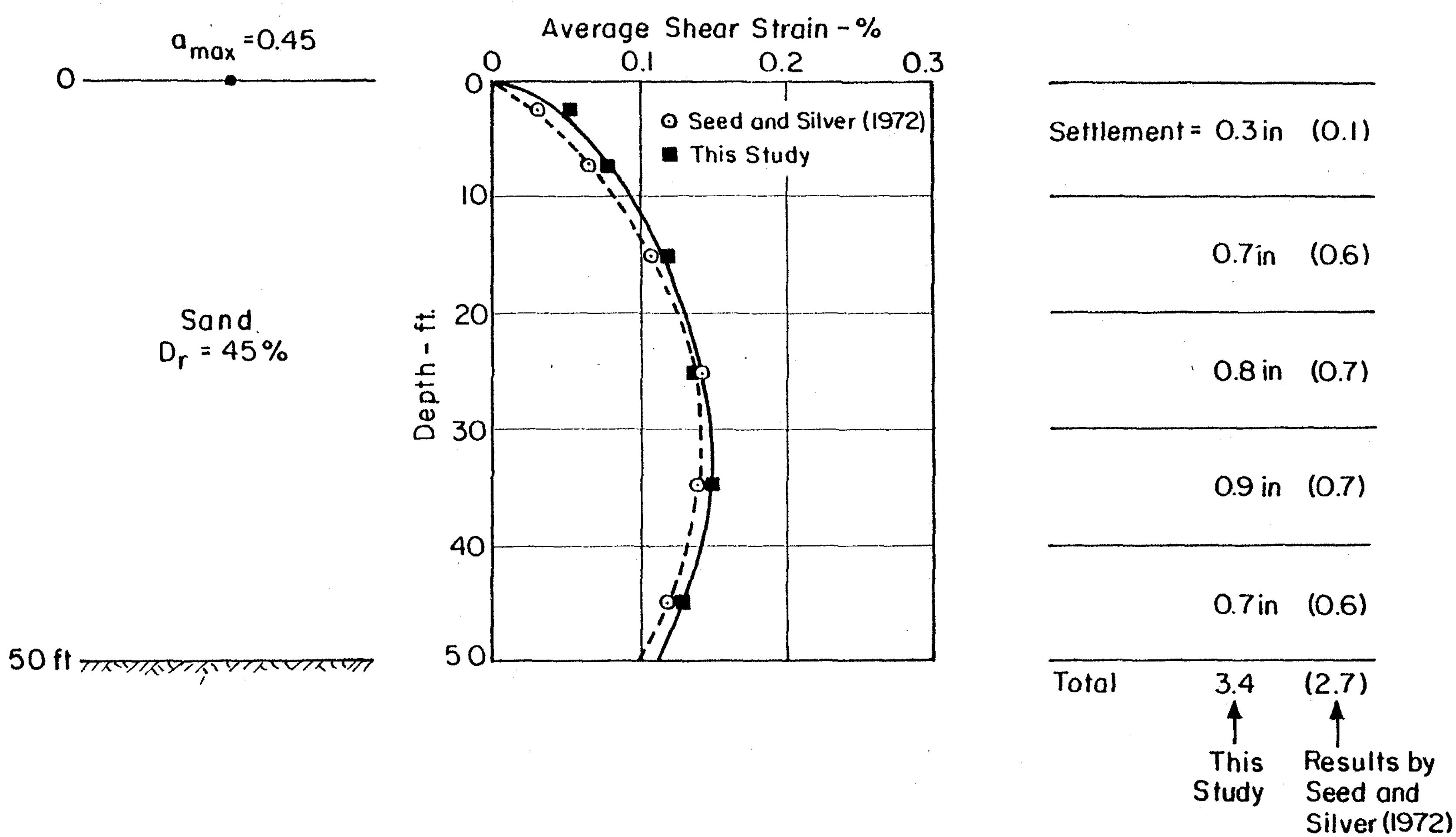


FIG. 16 COMPUTATION OF SETTLEMENT FOR 50 FT DEEP SAND LAYER

References

Building Research Institute, Ministry of Construction, "Niigata Earthquake and Damage to Reinforced Concrete Buildings in Niigata City," Report of Building Research Institute, No. 42, 1965. (in Japanese)

Iwasaki, T., Tatsuoka, F. and Takagi, Y., "Shear Modulus of Sands Under Cyclic Torsional Shear Loading," Soils and Foundations, Vol. 18, No. 1, March 1978, pp. 39-50.

Kovacs, W. D., Yokel, F. Y., Salomone, L. A. and Holtz, R. D., "Liquefaction Potential and the International SPT," Proceedings, 8th World Conference on Earthquake Engineering, San Francisco, July, 1984, Vol. 3, pp. 263-268.

Lee, K. L. and Albaisa, A., "Earthquake Induced Settlements in Saturated Sands," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 100, No. GT4, April, 1974, pp. 387-406.

Meyerhof, G. G., "Discussion," Proceedings, 4th International Conference on Soil Mechanics and Foundation Engineering, Vol. 3, p. 110, 1957.

Mitchell, J. K., "Practical Problems from Surprising Soil Behavior," Terzaghi Lecture presented at the San Francisco Conference of the American Society of Civil Engineers, October 1 to 4, 1984.

Ohsaki, Y., "Effects of Sand Compaction on Liquefaction during Tokachioki Earthquake," Soils and Foundations, Vol. 10, No. 2, 1970, pp. 112-128.

Ohta, Y. and Goto, N., "Estimation of S-wave Velocity in Terms of Characteristic Indices of Soil," Butsuri-Tanko, Vol. 29, No. 4, 1976, pp. 34-41. (in Japanese)

Pyke, R., Seed, H. B. and Chan, C. K., "Settlement of Sands under Multidirectional Shaking," Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, No. GT4, April, 1975, pp. 379-398.

Seed, H. B., "Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground during Earthquakes," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT2, Feb., 1979, pp. 201-255.

Seed, H. B. and Idriss, I. M., "Soil Moduli and Damping Factors for Dynamic Response Analyses," Report No. EERC 70-10, Earthquake Engineering Research Center, University of California, Berkeley, 1970.

Seed, H. Bolton and Idriss, I. M., "Simplified Procedure for Evaluating Soil Liquefaction Potential," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. SM9, September, 1971.

Seed, H. B., Idriss, I. M. and Arango, I., "Evaluation of Liquefaction Potential Using Field Performance Data," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. GT3, March, 1983, pp. 458-482.

Seed, H. B. and Silver, M. L., "Settlement of Dry Sands during Earthquakes," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 98, No. SM4, April, 1972, pp. 381-397.

Seed, H. Bolton, Tokimatsu, K. and Harder, L., "The Influence of SPT Procedures in Evaluating Soil Liquefaction Resistance," Report No. UCB/EERC-84-15, Earthquake Engineering Research Center, University of California, Berkeley, California, October, 1984(a).

Seed, H. Bolton, Wong, Robert T., Idriss, I. M. and Tokimatsu, K., "Moduli and Damping Factors for Dynamic Analyses of Cohesionless Soils," Report No. UCB/EERC-84/14, Earthquake Engineering Research Center, University of California, Berkeley, California, September, 1984(b).

Silver, M. L. and Seed, H. B., "Volume Changes in Sands during Cyclic Loading," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. SM9, Sept., 1971, pp. 1171-1182.

Tatsuoka, F., Iwasaki, T., Tokida, K., Yasuda, S., Hirose, M., Imai, T., Kon-no, M., "A Method for Estimating Undrained Cyclic Strength of Sandy Soils Using Standard Penetration Resistances," Soils and Foundations, Vol. 18, No. 3, pp. 43-58, Sept. 1978.

Tatsuoka, F., Sasaki, T. and Yamada, S., "Settlement in Saturated Sand Induced by Cyclic Undrained Simple Shear," Proceedings, 8th World Conference on Earthquake Engineering, San Francisco, Vol. 3, pp. 95-102, July 1984.

Tohno, I. and Yasuda, S., "Liquefaction of the Ground during the 1978 Miyagiken-oki Earthquake," Soils and Foundations, Vol. 21, No. 3, Sept. 1981, pp. 18-34.

Tokimatsu, K. and Yoshimi, Y., "Empirical Correlation of Soil Liquefaction Based on SPT N-Value and Fines Content," Soils and Foundations, Vol. 23, No. 4, pp. 56-74, Dec., 1983.

Tokimatsu, K. and Yoshimi, Y., "Criteria of Soil Liquefaction with SPT and Fines Content," Proceedings, 8th World Conference on Earthquake Engineering, San Francisco, Vol. 3, pp. 255-262, July, 1984.

Yoshimi, Y., Personal Communication, 1984.

Yoshimi, Y., Kuwabara, F. and Tokimatsu, K., "One-Dimensional Volume Change Characteristics of Sands under Very Low Confining Stresses," Soils and Foundations, Vol. 15, No. 3, Sept., 1975, pp. 51-60.

Appendix 1 - Nomenclature

a_{max}	maximum horizontal acceleration at the ground surface
C_{ER}	connection factor for the energy developed in the SPT determinations
C_N	correction factor in terms of effective stress
D_r	relative density
G_{eff}	effective shear modulus at induced strain level
G_{max}	shear modulus at low strain level
g	acceleration of gravity
$(K_2)_{max}$	soil modulus coefficient
M	earthquake magnitude
N	measured SPT N-value
N_J	SPT N-value in Japanese practice
N_{60}	SPT N-value determined by a method providing 60% of the theoretical free-fall energy to the drill rods
$(N_1)_{60}$	SPT N-value normalized to an effective overburden pressure of 1 tsf and to an effective energy delivered to the drill rods equal to 60% of the theoretical free-fall energy
r_d	stress reduction factor
r_m	scaling factor for stress ratio in terms of earthquake magnitude
γ_{eff}	effective shear strain induced by earthquake shaking
ε_c	volumetric strain
$\varepsilon_{c,N}$	volumetric strain after N cycles
σ_o	total overburden pressure
σ_m'	mean principal effective stress
σ_o'	effective overburden pressure
τ_{av}	average cyclic shear stress
τ_{max}	maximum cyclic shear stress

EARTHQUAKE ENGINEERING RESEARCH CENTER REPORTS

NOTE: Numbers in parentheses are Accession Numbers assigned by the National Technical Information Service; these are followed by a price code. Copies of the reports may be ordered from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia, 22161. Accession Numbers should be quoted on orders for reports (PB --- ---) and remittance must accompany each order. Reports without this information were not available at time of printing. The complete list of EERC reports (from EERC 67-1) is available upon request from the Earthquake Engineering Research Center, University of California, Berkeley, 47th Street and Hoffman Boulevard, Richmond, California 94804.

UCB/EERC-77/01 "PLUSH - A Computer Program for Probabilistic Finite Element Analysis of Seismic Soil-Structure Interaction," by M.P. Romo Organista, J. Lysmer and H.B. Seed - 1977 (PB81 177 651)A05

UCB/EERC-77/02 "Soil-Structure Interaction Effects at the Humboldt Bay Power Plant in the Ferndale Earthquake of June 7, 1975," by J.E. Valera, H.B. Seed, C.F. Tsai and J. Lysmer - 1977 (PB 265 795)A04

UCB/EERC-77/03 "Influence of Sample Disturbance on Sand Response to Cyclic Loading," by K. Mori, H.B. Seed and C.K. Chan - 1977 (PB 267 352)A04

UCB/EERC-77/04 "Seismological Studies of Strong Motion Records," by J. Shoja-Taheri - 1977 (PB 269 655)A10

UCB/EERC-77/05 Unassigned

UCB/EERC-77/06 "Developing Methodologies for Evaluating the Earthquake Safety of Existing Buildings," by No. 1 - B. Bresler; No. 2 - B. Bresler, T. Okada and D. Zisling; No. 3 - T. Okada and B. Bresler; No. 4 - V.V. Bertero and B. Bresler - 1977 (PB 267 354)A08

UCB/EERC-77/07 "A Literature Survey - Transverse Strength of Masonry Walls," by Y. Omote, R.L. Mayes, S.W. Chen and R.W. Clough - 1977 (PB 277 933)A07

UCB/EERC-77/08 "DRAIN-TABS: A Computer Program for Inelastic Earthquake Response of Three Dimensional Buildings," by R. Guendelman-Israel and G.H. Powell - 1977 (PB 270 693)A07

UCB/EERC-77/09 "SUBWALL: A Special Purpose Finite Element Computer Program for Practical Elastic Analysis and Design of Structural Walls with Substructure Option," by D.Q. Le, H. Peterson and E.P. Popov - 1977 (PB 270 567)A05

UCB/EERC-77/10 "Experimental Evaluation of Seismic Design Methods for Broad Cylindrical Tanks," by D.P. Clough (PB 272 280)A13

UCB/EERC-77/11 "Earthquake Engineering Research at Berkeley - 1976," - 1977 (PB 273 507)A09

UCB/EERC-77/12 "Automated Design of Earthquake Resistant Multistory Steel Building Frames," by N.D. Walker, Jr. - 1977 (PB 276 526)A09

UCB/EERC-77/13 "Concrete Confined by Rectangular Hoops Subjected to Axial Loads," by J. Vallenas, V.V. Bertero and E.P. Popov - 1977 (PB 275 165)A06

UCB/EERC-77/14 "Seismic Strain Induced in the Ground During Earthquakes," by Y. Sugimura - 1977 (PB 284 201)A04

UCB/EERC-77/15 Unassigned

UCB/EERC-77/16 "Computer Aided Optimum Design of Ductile Reinforced Concrete Moment Resisting Frames," by S.W. Zagajeski and V.V. Bertero - 1977 (PB 280 137)A07

UCB/EERC-77/17 "Earthquake Simulation Testing of a Stepping Frame with Energy-Absorbing Devices," by J.M. Kelly and D.F. Tsztoo - 1977 (PB 273 506)A04

UCB/EERC-77/18 "Inelastic Behavior of Eccentrically Braced Steel Frames under Cyclic Loadings," by C.W. Roeder and E.P. Popov - 1977 (PB 275 526)A15

UCB/EERC-77/19 "A Simplified Procedure for Estimating Earthquake-Induced Deformations in Dams and Embankments," by F.I. Makdisi and H.B. Seed - 1977 (PB 276 820)A04

UCB/EERC-77/20 "The Performance of Earth Dams during Earthquakes," by H.B. Seed, F.I. Makdisi and P. de Alba - 1977 (PB 276 821)A04

UCB/EERC-77/21 "Dynamic Plastic Analysis Using Stress Resultant Finite Element Formulation," by P. Lukkunapvasit and J.M. Kelly - 1977 (PB 275 453)A04

UCB/EERC-77/22 "Preliminary Experimental Study of Seismic Uplift of a Steel Frame," by R.W. Clough and A.A. Huckelbridge 1977 (PB 278 769)A08

UCB/EERC-77/23 "Earthquake Simulator Tests of a Nine-Story Steel Frame with Columns Allowed to Uplift," by A.A. Huckelbridge - 1977 (PB 277 944)A09

UCB/EERC-77/24 "Nonlinear Soil-Structure Interaction of Skew Highway Bridges," by M.-C. Chen and J. Penzien - 1977 (PB 276 176)A07

UCB/EERC-77/25 "Seismic Analysis of an Offshore Structure Supported on Pile Foundations," by D.D.-N. Liou and J. Penzien 1977 (PB 283 180)A06

UCB/EERC-77/26 "Dynamic Stiffness Matrices for Homogeneous Viscoelastic Half-Planes," by G. Dasgupta and A.K. Chopra - 1977 (PB 279 654)A06

UCB/EERC-77/27 "A Practical Soft Story Earthquake Isolation System," by J.M. Kelly, J.M. Eidinger and C.J. Derham - 1977 (PB 276 814)A07

UCB/EERC-77/28 "Seismic Safety of Existing Buildings and Incentives for Hazard Mitigation in San Francisco: An Exploratory Study," by A.J. Meltsner - 1977 (PB 281 970)A05

UCB/EERC-77/29 "Dynamic Analysis of Electrohydraulic Shaking Tables," by D. Rea, S. Abedi-Hayati and Y. Takahashi 1977 (PB 282 569)A04

UCB/EERC-77/30 "An Approach for Improving Seismic - Resistant Behavior of Reinforced Concrete Interior Joints," by B. Galunic, V.V. Bertero and E.P. Popov - 1977 (PB 290 870)A06

UCB/EERC-78/01 "The Development of Energy-Absorbing Devices for Aseismic Base Isolation Systems," by J.M. Kelly and D.F. Tsztoo - 1978 (PB 284 978)A04

UCB/EERC-78/02 "Effect of Tensile Prestrain on the Cyclic Response of Structural Steel Connections, by J.G. Bouwkamp and A. Mukhopadhyay - 1978

UCB/EERC-78/03 "Experimental Results of an Earthquake Isolation System using Natural Rubber Bearings," by J.M. Eidinger and J.M. Kelly - 1978 (PB 281 686)A04

UCB/EERC-78/04 "Seismic Behavior of Tall Liquid Storage Tanks," by A. Niwa - 1978 (PB 284 017)A14

UCB/EERC-78/05 "Hysteretic Behavior of Reinforced Concrete Columns Subjected to High Axial and Cyclic Shear Forces," by S.W. Zagajeski, V.V. Bertero and J.G. Bouwkamp - 1978 (PB 283 858)A13

UCB/EERC-78/06 "Three Dimensional Inelastic Frame Elements for the ANSR-I Program," by A. Riahi, D.G. Row and G.H. Powell - 1978 (PB 295 755)A04

UCB/EERC-78/07 "Studies of Structural Response to Earthquake Ground Motion," by O.A. Lopez and A.K. Chopra - 1978 (PB 282 790)A05

UCB/EERC-78/08 "A Laboratory Study of the Fluid-Structure Interaction of Submerged Tanks and Caissons in Earthquakes," by R.C. Byrd - 1978 (PB 284 957)A08

UCB/EERC-78/09 Unassigned

UCB/EERC-78/10 "Seismic Performance of Nonstructural and Secondary Structural Elements," by I. Sakamoto - 1978 (PB81 154 593)A05

UCB/EERC-78/11 "Mathematical Modelling of Hysteresis Loops for Reinforced Concrete Columns," by S. Nakata, T. Sproul and J. Penzien - 1978 (PB 298 274)A05

UCB/EERC-78/12 "Damageability in Existing Buildings," by T. Blejwas and B. Bresler - 1978 (PB 80 166 978)A05

UCB/EERC-78/13 "Dynamic Behavior of a Pedestal Base Multistory Building," by R.M. Stephen, E.L. Wilson, J.G. Bouwkamp and M. Button - 1978 (PB 286 650)A08

UCB/EERC-78/14 "Seismic Response of Bridges - Case Studies," by R.A. Imbsen, V. Nutt and J. Penzien - 1978 (PB 286 503)A10

UCB/EERC-78/15 "A Substructure Technique for Nonlinear Static and Dynamic Analysis," by D.G. Row and G.H. Powell - 1978 (PB 288 077)A10

UCB/EERC-78/16 "Seismic Risk Studies for San Francisco and for the Greater San Francisco Bay Area," by C.S. Oliveira - 1978 (PB 81 120 115)A07

UCB/EERC-78/17 "Strength of Timber Roof Connections Subjected to Cyclic Loads," by P. Gülkan, R.L. Mayes and R.W. Clough - 1978 (HUD-000 1491)A07

UCB/EERC-78/18 "Response of K-Braced Steel Frame Models to Lateral Loads," by J.G. Bouwkamp, R.M. Stephen and E.P. Popov - 1978

UCB/EERC-78/19 "Rational Design Methods for Light Equipment in Structures Subjected to Ground Motion," by J.L. Sackman and J.M. Kelly - 1978 (PB 292 357)A04

UCB/EERC-78/20 "Testing of a Wind Restraint for Aseismic Base Isolation," by J.M. Kelly and D.E. Chitty - 1978 (PB 292 833)A03

UCB/EERC-78/21 "APOLLO - A Computer Program for the Analysis of Pore Pressure Generation and Dissipation in Horizontal Sand Layers During Cyclic or Earthquake Loading," by P.P. Martin and H.B. Seed - 1978 (PB 292 835)A04

UCB/EERC-78/22 "Optimal Design of an Earthquake Isolation System," by M.A. Bhatti, K.S. Pister and E. Polak - 1978 (PB 294 735)A06

UCB/EERC-78/23 "MASH - A Computer Program for the Non-Linear Analysis of Vertically Propagating Shear Waves in Horizontally Layered Deposits," by P.P. Martin and H.B. Seed - 1978 (PB 293 101)A05

UCB/EERC-78/24 "Investigation of the Elastic Characteristics of a Three Story Steel Frame Using System Identification," by I. Kaya and H.D. McNiven - 1978 (PB 296 225)A06

UCB/EERC-78/25 "Investigation of the Nonlinear Characteristics of a Three-Story Steel Frame Using System Identification," by I. Kaya and H.D. McNiven - 1978 (PB 301 363)A05

UCB/EERC-78/26 "Studies of Strong Ground Motion in Taiwan," by Y.M. Hsiung, B.A. Bolt and J. Penzien - 1978 (PB 298 436)A06

UCB/EERC-78/27 "Cyclic Loading Tests of Masonry Single Piers: Volume 1 - Height to Width Ratio of 2," by P.A. Hidalgo, R.L. Mayes, H.D. McNiven and R.W. Clough - 1978 (PB 296 211)A07

UCB/EERC-78/28 "Cyclic Loading Tests of Masonry Single Piers: Volume 2 - Height to Width Ratio of 1," by S.-W.J. Chen, P.A. Hidalgo, R.L. Mayes, R.W. Clough and H.D. McNiven - 1978 (PB 296 212)A09

UCB/EERC-78/29 "Analytical Procedures in Soil Dynamics," by J. Lysmer - 1978 (PB 298 445)A06

UCB/EERC-79/01 "Hysteretic Behavior of Lightweight Reinforced Concrete Beam-Column Subassemblages," by B. Forzani, E.P. Popov and V.V. Bertero - April 1979(PB 298 267)A06

UCB/EERC-79/02 "The Development of a Mathematical Model to Predict the Flexural Response of Reinforced Concrete Beams to Cyclic Loads, Using System Identification," by J. Stanton & H. McNiven - Jan. 1979(PB 295 875)A10

UCB/EERC-79/03 "Linear and Nonlinear Earthquake Response of Simple Torsionally Coupled Systems," by C.L. Kan and A.K. Chopra - Feb. 1979(PB 298 262)A06

UCB/EERC-79/04 "A Mathematical Model of Masonry for Predicting its Linear Seismic Response Characteristics," by Y. Mengi and H.D. McNiven - Feb. 1979(PB 298 266)A06

UCB/EERC-79/05 "Mechanical Behavior of Lightweight Concrete Confined by Different Types of Lateral Reinforcement," by M.A. Manrique, V.V. Bertero and E.P. Popov - May 1979(PB 301 114)A06

UCB/EERC-79/06 "Static Tilt Tests of a Tall Cylindrical Liquid Storage Tank," by R.W. Clough and A. Niwa - Feb. 1979 (PB 301 167)A06

UCB/EERC-79/07 "The Design of Steel Energy Absorbing Restrainers and Their Incorporation into Nuclear Power Plants for Enhanced Safety: Volume 1 - Summary Report," by P.N. Spencer, V.F. Zackay, and E.R. Parker - Feb. 1979(UCB/EERC-79/07)A09

UCB/EERC-79/08 "The Design of Steel Energy Absorbing Restrainers and Their Incorporation into Nuclear Power Plants for Enhanced Safety: Volume 2 - The Development of Analyses for Reactor System Piping,""Simple Systems" by M.C. Lee, J. Penzien, A.K. Chopra and K, Suzuki "Complex Systems" by G.H. Powell, E.L. Wilson, R.W. Clough and D.G. Row - Feb. 1979(UCB/EERC-79/08)A10

UCB/EERC-79/09 "The Design of Steel Energy Absorbing Restrainers and Their Incorporation into Nuclear Power Plants for Enhanced Safety: Volume 3 - Evaluation of Commercial Steels," by W.S. Owen, R.M.N. Pelloux, R.O. Ritchie, M. Faral, T. Ohhashi, J. Toplosky, S.J. Hartman, V.F. Zackay and E.R. Parker - Feb. 1979(UCB/EERC-79/09)A04

UCB/EERC-79/10 "The Design of Steel Energy Absorbing Restrainers and Their Incorporation into Nuclear Power Plants for Enhanced Safety: Volume 4 - A Review of Energy-Absorbing Devices," by J.M. Kelly and M.S. Skinner - Feb. 1979(UCB/EERC-79/10)A04

UCB/EERC-79/11 "Conservatism In Summation Rules for Closely Spaced Modes," by J.M. Kelly and J.L. Sackman - May 1979(PB 301 328)A03

UCB/EERC-79/12 "Cyclic Loading Tests of Masonry Single Piers; Volume 3 - Height to Width Ratio of 0.5," by P.A. Hidalgo, R.L. Mayes, H.D. McNiven and R.W. Clough - May 1979(PB 301 321)A08

UCB/EERC-79/13 "Cyclic Behavior of Dense Course-Grained Materials in Relation to the Seismic Stability of Dams," by N.G. Banerjee, H.B. Seed and C.K. Chan - June 1979(PB 301 373)A13

UCB/EERC-79/14 "Seismic Behavior of Reinforced Concrete Interior Beam-Column Subassemblages," by S. Viwathanatepa, E.P. Popov and V.V. Bertero - June 1979(PB 301 326)A10

UCB/EERC-79/15 "Optimal Design of Localized Nonlinear Systems with Dual Performance Criteria Under Earthquake Excitations," by M.A. Bhatti - July 1979(PB 80 167 109)A06

UCB/EERC-79/16 "OPTDYN - A General Purpose Optimization Program for Problems with or without Dynamic Constraints," by M.A. Bhatti, E. Polak and K.S. Pister - July 1979(PB 80 167 091)A05

UCB/EERC-79/17 "ANSR-II, Analysis of Nonlinear Structural Response, Users Manual," by D.P. Mondkar and G.H. Powell July 1979(PB 80 113 301)A05

UCB/EERC-79/18 "Soil Structure Interaction in Different Seismic Environments," A. Gomez-Masso, J. Lysmer, J.-C. Chen and H.B. Seed - August 1979(PB 80 101 520)A04

UCB/EERC-79/19 "ARMA Models for Earthquake Ground Motions," by M.K. Chang, J.W. Kwiatkowski, R.F. Nau, R.M. Oliver and K.S. Pister - July 1979(PB 301 166)A05

UCB/EERC-79/20 "Hysteretic Behavior of Reinforced Concrete Structural Walls," by J.M. Vallenas, V.V. Bertero and E.P. Popov - August 1979(PB 80 165 905)A12

UCB/EERC-79/21 "Studies on High-Frequency Vibrations of Buildings - 1: The Column Effect," by J. Lubliner - August 1979 (PB 80 158 553)A03

UCB/EERC-79/22 "Effects of Generalized Loadings on Bond Reinforcing Bars Embedded in Confined Concrete Blocks," by S. Viwathanatepa, E.P. Popov and V.V. Bertero - August 1979(PB 81 124 018)A14

UCB/EERC-79/23 "Shaking Table Study of Single-Story Masonry Houses, Volume 1: Test Structures 1 and 2," by P. Gülkan, R.L. Mayes and R.W. Clough - Sept. 1979 (HUD-000 1763)A12

UCB/EERC-79/24 "Shaking Table Study of Single-Story Masonry Houses, Volume 2: Test Structures 3 and 4," by P. Gülkan, R.L. Mayes and R.W. Clough - Sept. 1979 (HUD-000 1836)A12

UCB/EERC-79/25 "Shaking Table Study of Single-Story Masonry Houses, Volume 3: Summary, Conclusions and Recommendations," by R.W. Clough, R.L. Mayes and P. Gülkan - Sept. 1979 (HUD-000 1837)A06

UCB/EERC-79/26 "Recommendations for a U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing Facilities," by U.S.-Japan Planning Group - Sept. 1979(PB 301 407)A06

UCB/EERC-79/27 "Earthquake-Induced Liquefaction Near Lake Amatitlan, Guatemala," by H.B. Seed, I. Arango, C.K. Chan, A. Gomez-Masso and R. Grant de Ascoli - Sept. 1979(NUREG-CR1341)A03

UCB/EERC-79/28 "Infill Panels: Their Influence on Seismic Response of Buildings," by J.W. Axley and V.V. Bertero Sept. 1979(PB 80 163 371)A10

UCB/EERC-79/29 "3D Truss Bar Element (Type 1) for the ANSR-II Program," by D.P. Mondkar and G.H. Powell - Nov. 1979 (PB 80 169 709)A02

UCB/EERC-79/30 "2D Beam-Column Element (Type 5 - Parallel Element Theory) for the ANSR-II Program," by D.G. Row, G.H. Powell and D.P. Mondkar - Dec. 1979(PB 80 167 224)A03

UCB/EERC-79/31 "3D Beam-Column Element (Type 2 - Parallel Element Theory) for the ANSR-II Program," by A. Riahi, G.H. Powell and D.P. Mondkar - Dec. 1979(PB 80 167 216)A03

UCB/EERC-79/32 "On Response of Structures to Stationary Excitation," by A. Der Kiureghian - Dec. 1979(PB 80166 929)A03

UCB/EERC-79/33 "Undisturbed Sampling and Cyclic Load Testing of Sands," by S. Singh, H.B. Seed and C.K. Chan Dec. 1979(ADA 087 298)A07

UCB/EERC-79/34 "Interaction Effects of Simultaneous Torsional and Compressional Cyclic Loading of Sand," by P.M. Griffin and W.N. Houston - Dec. 1979(ADA 092 352)A15

UCB/EERC-80/01 "Earthquake Response of Concrete Gravity Dams Including Hydrodynamic and Foundation Interaction Effects," by A.K. Chopra, P. Chakrabarti and S. Gupta - Jan. 1980(AD-A087297)A10

UCB/EERC-80/02 "Rocking Response of Rigid Blocks to Earthquakes," by C.S. Yim, A.K. Chopra and J. Penzien - Jan. 1980 (PB80 166 002)A04

UCB/EERC-80/03 "Optimum Inelastic Design of Seismic-Resistant Reinforced Concrete Frame Structures," by S.W. Zagajeski and V.V. Bertero - Jan. 1980(PB80 164 635)A06

UCB/EERC-80/04 "Effects of Amount and Arrangement of Wall-Panel Reinforcement on Hysteretic Behavior of Reinforced Concrete Walls," by R. Iliya and V.V. Bertero - Feb. 1980(PB81 122 525)A09

UCB/EERC-80/05 "Shaking Table Research on Concrete Dam Models," by A. Niwa and R.W. Clough - Sept. 1980(PB81 122 368)A06

UCB/EERC-80/06 "The Design of Steel Energy-Absorbing Restrainers and their Incorporation into Nuclear Power Plants for Enhanced Safety (Vol 1A): Piping with Energy Absorbing Restrainers: Parameter Study on Small Systems," by G.H. Powell, C. Oughourlian and J. Simons - June 1980

UCB/EERC-80/07 "Inelastic Torsional Response of Structures Subjected to Earthquake Ground Motions," by Y. Yamazaki April 1980(PB81 122 327)A08

UCB/EERC-80/08 "Study of X-Braced Steel Frame Structures Under Earthquake Simulation," by Y. Ghanaat - April 1980 (PB81 122 335)A11

UCB/EERC-80/09 "Hybrid Modelling of Soil-Structure Interaction," by S. Gupta, T.W. Lin, J. Penzien and C.S. Yeh May 1980(PB81 122 319)A07

UCB/EERC-80/10 "General Applicability of a Nonlinear Model of a One Story Steel Frame," by B.I. Sveinsson and H.D. McNiven - May 1980(PB81 124 877)A06

UCB/EERC-80/11 "A Green-Function Method for Wave Interaction with a Submerged Body," by W. Kioka - April 1980 (PB81 122 269)A07

UCB/EERC-80/12 "Hydrodynamic Pressure and Added Mass for Axisymmetric Bodies," by F. Nilrat - May 1980(PB81 122 343)A08

UCB/EERC-80/13 "Treatment of Non-Linear Drag Forces Acting on Offshore Platforms," by B.V. Dao and J. Penzien May 1980(PB81 153 413)A07

UCB/EERC-80/14 "2D Plane/Axisymmetric Solid Element (Type 3 - Elastic or Elastic-Perfectly Plastic) for the ANSR-II Program," by D.P. Mondkar and G.H. Powell - July 1980(PB81 122 350)A03

UCB/EERC-80/15 "A Response Spectrum Method for Random Vibrations," by A. Der Kiureghian - June 1980(PB81 122 301)A03

UCB/EERC-80/16 "Cyclic Inelastic Buckling of Tubular Steel Braces," by V.A. Zayas, E.P. Popov and S.A. Mahin June 1980(PB81 124 885)A10

UCB/EERC-80/17 "Dynamic Response of Simple Arch Dams Including Hydrodynamic Interaction," by C.S. Porter and A.K. Chopra - July 1980(PB81 124 000)A13

UCB/EERC-80/18 "Experimental Testing of a Friction Damped Aseismic Base Isolation System with Fail-Safe Characteristics," by J.M. Kelly, K.E. Beucke and M.S. Skinner - July 1980(PB81 148 595)A04

UCB/EERC-80/19 "The Design of Steel Energy-Absorbing Restrainers and their Incorporation into Nuclear Power Plants for Enhanced Safety (Vol 1B): Stochastic Seismic Analyses of Nuclear Power Plant Structures and Piping Systems Subjected to Multiple Support Excitations," by M.C. Lee and J. Penzien - June 1980

UCB/EERC-80/20 "The Design of Steel Energy-Absorbing Restrainers and their Incorporation into Nuclear Power Plants for Enhanced Safety (Vol 1C): Numerical Method for Dynamic Substructure Analysis," by J.M. Dickens and E.L. Wilson - June 1980

UCB/EERC-80/21 "The Design of Steel Energy-Absorbing Restrainers and their Incorporation into Nuclear Power Plants for Enhanced Safety (Vol 2): Development and Testing of Restraints for Nuclear Piping Systems," by J.M. Kelly and M.S. Skinner - June 1980

UCB/EERC-80/22 "3D Solid Element (Type 4-Elastic or Elastic-Perfectly-Plastic) for the ANSR-II Program," by D.P. Mondkar and G.H. Powell - July 1980(PB81 123 242)A03

UCB/EERC-80/23 "Gap-Friction Element (Type 5) for the ANSR-II Program," by D.P. Mondkar and G.H. Powell - July 1980 (PB81 122 285)A03

UCB/EERC-80/24 "U-Bar Restraint Element (Type 11) for the ANSR-II Program," by C. Oughourlian and G.H. Powell July 1980(PB81 122 293)A03

UCB/EERC-80/25 "Testing of a Natural Rubber Base Isolation System by an Explosively Simulated Earthquake," by J.M. Kelly - August 1980(PB81 201 360)A04

UCB/EERC-80/26 "Input Identification from Structural Vibrational Response," by Y. Hu - August 1980(PB81 152 308)A05

UCB/EERC-80/27 "Cyclic Inelastic Behavior of Steel Offshore Structures," by V.A. Zayas, S.A. Mahin and E.P. Popov August 1980(PB81 196 180)A15

UCB/EERC-80/28 "Shaking Table Testing of a Reinforced Concrete Frame with Biaxial Response," by M.G. Oliva October 1980(PB81 154 304)A10

UCB/EERC-80/29 "Dynamic Properties of a Twelve-Story Prefabricated Panel Building," by J.G. Bouwkamp, J.P. Kollegger and R.M. Stephen - October 1980(PB82 117 128)A06

UCB/EERC-80/30 "Dynamic Properties of an Eight-Story Prefabricated Panel Building," by J.G. Bouwkamp, J.P. Kollegger and R.M. Stephen - October 1980(PB81 200 313)A05

UCB/EERC-80/31 "Predictive Dynamic Response of Panel Type Structures Under Earthquakes," by J.P. Kollegger and J.G. Bouwkamp - October 1980(PB81 152 316)A04

UCB/EERC-80/32 "The Design of Steel Energy-Absorbing Restrainers and their Incorporation into Nuclear Power Plants for Enhanced Safety (Vol 3): Testing of Commercial Steels in Low-Cycle Torsional Fatigue," by P. Spencer, E.R. Parker, E. Jongewaard and M. Drory

UCB/EERC-80/33 "The Design of Steel Energy-Absorbing Restrainers and their Incorporation into Nuclear Power Plants for Enhanced Safety (Vol 4): Shaking Table Tests of Piping Systems with Energy-Absorbing Restrainers," by S.F. Stiemer and W.G. Godden - Sept. 1980

UCB/EERC-80/34 "The Design of Steel Energy-Absorbing Restrainers and their Incorporation into Nuclear Power Plants for Enhanced Safety (Vol 5): Summary Report," by P. Spencer

UCB/EERC-80/35 "Experimental Testing of an Energy-Absorbing Base Isolation System," by J.M. Kelly, M.S. Skinner and K.E. Beucke - October 1980(PB81 154 072)A04

UCB/EERC-80/36 "Simulating and Analyzing Artificial Non-Stationary Earthquake Ground Motions," by R.F. Nau, R.M. Oliver and K.S. Pister - October 1980(PB81 153 397)A04

UCB/EERC-80/37 "Earthquake Engineering at Berkeley - 1980," - Sept. 1980(PB81 205 874)A09

UCB/EERC-80/38 "Inelastic Seismic Analysis of Large Panel Buildings," by V. Schricker and G.H. Powell - Sept. 1980 (PB81 154 338)A13

UCB/EERC-80/39 "Dynamic Response of Embankment, Concrete-Gravity and Arch Dams Including Hydrodynamic Interaction," by J.F. Hall and A.K. Chopra - October 1980(PB81 152 324)A11

UCB/EERC-80/40 "Inelastic Buckling of Steel Struts Under Cyclic Load Reversal," by R.G. Black, W.A. Wenger and E.P. Popov - October 1980(PB81 154 312)A08

UCB/EERC-80/41 "Influence of Site Characteristics on Building Damage During the October 3, 1974 Lima Earthquake," by P. Repetto, I. Arango and H.B. Seed - Sept. 1980(PB81 161 739)A05

UCB/EERC-80/42 "Evaluation of a Shaking Table Test Program on Response Behavior of a Two Story Reinforced Concrete Frame," by J.M. Blondet, R.W. Clough and S.A. Mahin

UCB/EERC-80/43 "Modelling of Soil-Structure Interaction by Finite and Infinite Elements," by F. Medina - December 1980(PB81 229 270)A04

UCB/EERC-81/01 "Control of Seismic Response of Piping Systems and Other Structures by Base Isolation," edited by J.M. Kelly - January 1981 (PB81 200 735)A05

UCB/EERC-81/02 "OPTNSR - An Interactive Software System for Optimal Design of Statically and Dynamically Loaded Structures with Nonlinear Response," by M.A. Bhatti, V. Ciampi and K.S. Pister - January 1981 (PB81 218 851)A09

UCB/EERC-81/03 "Analysis of Local Variations in Free Field Seismic Ground Motions," by J.-C. Chen, J. Lysmer and H.B. Seed - January 1981 (AD-A099508)A13

UCB/EERC-81/04 "Inelastic Structural Modeling of Braced Offshore Platforms for Seismic Loading," by V.A. Zayas, P.-S.B. Shing, S.A. Mahin and E.P. Popov - January 1981(PB82 138 777)A07

UCB/EERC-81/05 "Dynamic Response of Light Equipment in Structures," by A. Der Kiureghian, J.L. Sackman and B. Nour-Omid - April 1981 (PB81 218 497)A04

UCB/EERC-81/06 "Preliminary Experimental Investigation of a Broad Base Liquid Storage Tank," by J.G. Bouwkamp, J.P. Kollegger and R.M. Stephen - May 1981(PB82 140 385)A03

UCB/EERC-81/07 "The Seismic Resistant Design of Reinforced Concrete Coupled Structural Walls," by A.E. Aktan and V.V. Bertero - June 1981(PB82 113 358)A11

UCB/EERC-81/08 "The Undrained Shearing Resistance of Cohesive Soils at Large Deformations," by M.R. Pyles and H.B. Seed - August 1981

UCB/EERC-81/09 "Experimental Behavior of a Spatial Piping System with Steel Energy Absorbers Subjected to a Simulated Differential Seismic Input," by S.F. Stiemer, W.G. Godden and J.M. Kally - July 1981

UCB/EERC-81/10 "Evaluation of Seismic Design Provisions for Masonry in the United States," by B.I. Sveinsson, R.L. Mayes and H.D. McNiven - August 1981 (PB82 166 075)A08

UCB/EERC-81/11 "Two-Dimensional Hybrid Modelling of Soil-Structure Interaction," by T.-J. Tzong, S. Gupta and J. Penzien - August 1981(PB82 142 118)A04

UCB/EERC-81/12 "Studies on Effects of Infills in Seismic Resistant R/C Construction," by S. Brokken and V.V. Bertero - September 1981 (PB82 166 190)A09

UCB/EERC-81/13 "Linear Models to Predict the Nonlinear Seismic Behavior of a One-Story Steel Frame," by H. Valdimarsson, A.H. Shah and H.D. McNiven - September 1981(PB82 138 793)A07

UCB/EERC-81/14 "TLUSH: A Computer Program for the Three-Dimensional Dynamic Analysis of Earth Dams," by T. Kagawa, L.H. Mejia, H.B. Seed and J. Lysmer - September 1981(PB82 139 940)A06

UCB/EERC-81/15 "Three Dimensional Dynamic Response Analysis of Earth Dams," by L.H. Mejia and H.B. Seed - September 1981 (PB82 137 274)A12

UCB/EERC-81/16 "Experimental Study of Lead and Elastomeric Dampers for Base Isolation Systems," by J.M. Kelly and S.B. Hodder - October 1981 (PB82 166 182)A05

UCB/EERC-81/17 "The Influence of Base Isolation on the Seismic Response of Light Secondary Equipment," by J.M. Kelly - April 1981 (PB82 255 266)A04

UCB/EERC-81/18 "Studies on Evaluation of Shaking Table Response Analysis Procedures," by J. Marcial Blondet - November 1981 (PB82 197 278)A10

UCB/EERC-81/19 "DELIGHT.STRUCT: A Computer-Aided Design Environment for Structural Engineering," by R.J. Balling, K.S. Pister and E. Polak - December 1981 (PB82 218 496)A07

UCB/EERC-81/20 "Optimal Design of Seismic-Resistant Planar Steel Frames," by R.J. Balling, V. Ciampi, K.S. Pister and E. Polak - December 1981 (PB82 220 179)A07

UCB/EERC-82/01 "Dynamic Behavior of Ground for Seismic Analysis of Lifeline Systems," by T. Sato and A. Der Kiureghian - January 1982 (PB82 218 926)A05

UCB/EERC-82/02 "Shaking Table Tests of a Tubular Steel Frame Model," by Y. Ghanaat and R. W. Clough - January 1982 (PB82 220 161)A07

UCB/EERC-82/03 "Behavior of a Piping System under Seismic Excitation: Experimental Investigations of a Spatial Piping System supported by Mechanical Shock Arrestors and Steel Energy Absorbing Devices under Seismic Excitation," by S. Schneider, H.-M. Lee and W. G. Godden - May 1982 (PB83 172 544)A09

UCB/EERC-82/04 "New Approaches for the Dynamic Analysis of Large Structural Systems," by E. L. Wilson - June 1982 (PB83 148 080)A05

UCB/EERC-82/05 "Model Study of Effects of Damage on the Vibration Properties of Steel Offshore Platforms," by F. Shahrivar and J. G. Bouwkamp - June 1982 (PB83 148 742)A10

UCB/EERC-82/06 "States of the Art and Practice in the Optimum Seismic Design and Analytical Response Prediction of R/C Frame-Wall Structures," by A. E. Aktan and V. V. Bertero - July 1982 (PB83 147 736)A05

UCB/EERC-82/07 "Further Study of the Earthquake Response of a Broad Cylindrical Liquid-Storage Tank Model," by G. C. Manos and R. W. Clough - July 1982 (PB83 147 744)A11

UCB/EERC-82/08 "An Evaluation of the Design and Analytical Seismic Response of a Seven Story Reinforced Concrete Frame - Wall Structure," by F. A. Charney and V. V. Bertero - July 1982(PB83 157 628)A09

UCB/EERC-82/09 "Fluid-Structure Interactions: Added Mass Computations for Incompressible Fluid," by J. S.-H. Kuo - August 1982 (PB83 156 281)A07

UCB/EERC-82/10 "Joint-Opening Nonlinear Mechanism: Interface Smeared Crack Model," by J. S.-H. Kuo - August 1982 (PB83 149 195)A05

UCB/EERC-82/11 "Dynamic Response Analysis of Techi Dam," by R. W. Clough, R. M. Stephen and J. S.-H. Kuo - August 1982 (PB83 147 496)A06

UCB/EERC-82/12 "Prediction of the Seismic Responses of R/C Frame-Coupled Wall Structures," by A. E. Aktan, V. V. Bertero and M. Piazza - August 1982 (PB83 149 203)A09

UCB/EERC-82/13 "Preliminary Report on the SMART 1 Strong Motion Array in Taiwan," by B. A. Bolt, C. H. Loh, J. Penzien, Y. B. Tsai and Y. T. Yeh - August 1982 (PB83 159 400)A10

UCB/EERC-82/14 "Shaking-Table Studies of an Eccentrically X-Braced Steel Structure," by M. S. Yang - September 1982

UCB/EERC-82/15 "The Performance of Stairways in Earthquakes," by C. Roha, J. W. Axley and V. V. Bertero - September 1982 (PB83 157 693)A07

UCB/EERC-82/16 "The Behavior of Submerged Multiple Bodies in Earthquakes," by W.-G. Liao - Sept. 1982 (PB83 158 709)A07

UCB/EERC-82/17 "Effects of Concrete Types and Loading Conditions on Local Bond-Slip Relationships," by A. D. Cowell, E. P. Popov and V. V. Bertero - September 1982 (PB83 153 577)A04

UCB/EERC-82/18 "Mechanical Behavior of Shear Wall Vertical Boundary Members: An Experimental Investigation," by M. T. Wagner and V. V. Bertero - October 1982 (PB83 159 764)A05

UCB/EERC-82/19 "Experimental Studies of Multi-support Seismic Loading on Piping Systems," by J. M. Kelly and A. D. Cowell - November 1982

UCB/EERC-82/20 "Generalized Plastic Hinge Concepts for 3D Beam-Column Elements," by P. F.-S. Chen and G. H. Powell - November 1982

UCB/EERC-82/21 "ANSR-III: General Purpose Computer Program for Nonlinear Structural Analysis," by C. V. Oughourlian and G. H. Powell - November 1982

UCB/EERC-82/22 "Solution Strategies for Statically Loaded Nonlinear Structures," by J. W. Simons and G. H. Powell - November 1982

UCB/EERC-82/23 "Analytical Model of Deformed Bar Anchorages under Generalized Excitations," by V. Ciampi, R. Eligehausen, V. V. Bertero and E. P. Popov - November 1982 (PB83 169 532)A06

UCB/EERC-82/24 "A Mathematical Model for the Response of Masonry Walls to Dynamic Excitations," by H. Sucuoğlu, Y. Mengi and H. D. McNiven - November 1982 (PB83 169 011)A07

UCB/EERC-82/25 "Earthquake Response Considerations of Broad Liquid Storage Tanks," by F. J. Cambra - November 1982

UCB/EERC-82/26 "Computational Models for Cyclic Plasticity, Rate Dependence and Creep," by B. Mosaddad and G. H. Powell - November 1982

UCB/EERC-82/27 "Inelastic Analysis of Piping and Tubular Structures," by M. Mahasuverachai and G. H. Powell - November 1982

UCB/EERC-83/01 "The Economic Feasibility of Seismic Rehabilitation of Buildings by Base Isolation," by J. M. Kelly - January 1983

UCB/EERC-83/02 "Seismic Moment Connections for Moment-Resisting Steel Frames," by E. P. Popov - January 1983

UCB/EERC-83/03 "Design of Links and Beam-to-Column Connections for Eccentrically Braced Steel Frames," by E. P. Popov and J. O. Malley - January 1983

UCB/EERC-83/04 "Numerical Techniques for the Evaluation of Soil-Structure Interaction Effects in the Time Domain," by E. Bayo and E. L. Wilson - February 1983

UCB/EERC-83/05 "A Transducer for Measuring the Internal Forces in the Columns of a Frame-Wall Reinforced Concrete Structure," by R. Sause and V. V. Bertero - May 1983

UCB/EERC-83/06 "Dynamic Interactions between Floating Ice and Offshore Structures," by P. Croteau - May 1983

UCB/EERC-83/07 "Dynamic Analysis of Multiply Tuned and Arbitrarily Supported Secondary Systems," by T. Igusa and A. Der Kiureghian - June 1983

UCB/EERC-83/08 "A Laboratory Study of Submerged Multi-body Systems in Earthquakes," by G. R. Ansari - June 1983

UCB/EERC-83/09 "Effects of Transient Foundation Uplift on Earthquake Response of Structures," by C.-S. Yim and A. K. Chopra - June 1983

UCB/EERC-83/10 "Optimal Design of Friction-Braced Frames under Seismic Loading," by M. A. Austin and K. S. Pister - June 1983

UCB/EERC-83/11 "Shaking Table Study of Single-Story Masonry Houses: Dynamic Performance under Three Component Seismic Input and Recommendations," by G. C. Manos, R. W. Clough and R. L. Mayes - June 1983

UCB/EERC-83/12 "Experimental Error Propagation in Pseudodynamic Testing," by P. B. Shing and S. A. Mahin - June 1983

UCB/EERC-83/13 "Experimental and Analytical Predictions of the Mechanical Characteristics of a 1/5-scale Model of a 7-story R/C Frame-Wall Building Structure," by A. E. Aktan, V. V. Bertero, A. A. Chowdhury and T. Nagashima - August 1983

UCB/EERC-83/14 "Shaking Table Tests of Large-Panel Precast Concrete Building System Assemblages," by M. G. Oliva and R. W. Clough - August 1983

UCB/EERC-83/15 "Seismic Behavior of Active Beam Links in Eccentrically Braced Frames," by K. D. Hjelmstad and E. P. Popov - July 1983

UCB/EERC-83/16 "System Identification of Structures with Joint Rotation," by J. S. Dimsdale and H. D. McNiven - July 1983

UCB/EERC-83/17 "Construction of Inelastic Response Spectra for Single-Degree-of-Freedom Systems," by S. Mahin and J. Lin - July 1983

.RC-83/18 "Interactive Computer Analysis Methods for Predicting the Inelastic Cyclic Behaviour of Structural Sections," by S. Kaba and S. Mahin - July 1983 (PB84 192 012) A06

:ERC-83/19 "Effects of Bond Deterioration on Hysteretic Behavior of Reinforced Concrete Joints," by F.C. Filippou, E.P. Popov and V.V. Bertero - August 1983 (PB84 192 020) A10

/EERC-83/20 "Analytical and Experimental Correlation of Large-Panel Precast Building System Performance," by M.G. Oliva, R.W. Clough, M. Velkov, P. Gavrilovic and J. Petrovski - November 1983

3/EERC-83/21 "Mechanical Characteristics of Materials Used in a 1/5 Scale Model of a 7-Story Reinforced Concrete Test Structure," by V.V. Bertero, A.E. Aktan, H.G. Harris and A.A. Chowdhury - September 1983 (PB84 193 697) A05

UCB/EERC-83/22 "Hybrid Modelling of Soil-Structure Interaction in Layered Media," by T.-J. Tzong and J. Penzien - October 1983 (PB84 192 178) A08

UCB/EERC-83/23 "Local Bond Stress-Slip Relationships of Deformed Bars under Generalized Excitations," by R. Eligehausen, E.P. Popov and V.V. Bertero - October 1983 (PB84 192 848) A09

UCB/EERC-83/24 "Design Considerations for Shear Links in Eccentrically Braced Frames," by J.O. Malley and E.P. Popov - November 1983 (PB84 192 186) A07

UCB/EERC-84/01 "Pseudodynamic Test Method for Seismic Performance Evaluation: Theory and Implementation," by P.-S. B. Shing and S. A. Mahin - January 1984 (PB84 190 644) A08

UCB/EERC-84/02 "Dynamic Response Behavior of Xiang Hong Dian Dam," by R.W. Clough, K.-T. Chang, H.-Q. Chen, R.M. Stephen, G.-L. Wang, and Y. Ghanaat - April 1984

UCB/EERC-84/03 "Refined Modelling of Reinforced Concrete Columns for Seismic Analysis," by S.A. Kaba and S.A. Mahin - April, 1984

UCB/EERC-84/04 "A New Floor Response Spectrum Method for Seismic Analysis of Multiply Supported Secondary Systems," by A. Asfura and A. Der Kiureghian - June 1984

UCB/EERC-84/05 "Earthquake Simulation Tests and Associated Studies of a 1/5th-scale Model of a 7-Story R/C Frame-Wall Test Structure," by V.V. Bertero, A.E. Aktan, F.A. Charney and R. Sause - June 1984

UCB/EERC-84/06 "R/C Structural Walls: Seismic Design for Shear," by A.E. Aktan and V.V. Bertero

UCB/EERC-84/07 "Behavior of Interior and Exterior Flat-Plate Connections subjected to Inelastic Load Reversals," by H.L. Zee and J.P. Moehle

UCB/EERC-84/08 "Experimental Study of the Seismic Behavior of a two-story Flat-Plate Structure," by J.W. Diebold and J.P. Moehle

UCB/EERC-84/09 "Phenomenological Modeling of Steel Braces under Cyclic Loading," by K. Ikeda, S.A. Mahin and S.N. Dermitzakis

UCB/EERC-84/10 "Earthquake Analysis and Response of Concrete Gravity Dams," by G. Fenves and A.K. Chopra

UCB/EERC-84/11 "EAGD-84: A Computer Program for Earthquake Analysis of Concrete Gravity Dams," by G. Fenves and A.K. Chopra

UCB/EERC-84/12 "A Refined Physical Theory Model for Predicting the Seismic Behavior of Braced Steel Frames," by K. Ikeda and S.A. Mahin

UCB/EERC-84/13 "Earthquake Engineering Research at Berkeley - 1984"

UCB/EERC-84/14 "Moduli and Damping Factors for Dynamic Analyses of Cohesionless Soils," by H.B. Seed, R.T. Wong, I.M. Idriss and K. Tokimatsu - September 1984

UCB/EERC-84/15 "The Influence of SPT Procedures in Soil Liquefaction Resistance Evaluations," by H.B. Seed, K. Tokimatsu and L.H. Harder - October 1984

UCB/EERC-84/16 "Simplified Procedures for the Evaluation of Settlements in Sands Due to Earthquake Shaking," by K. Tokimatsu and H.B. Seed - October 1984