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Spectral curves -versus- distance and dynamic site-periods

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ABSTRACT: Spectral shapes from recorded motions change in a consistent fashion patern depending on local soil conditions, characteristics of earthquake motions and distances from zones of energy release. Since within the area of a city or so, there may be no significant differences in seismicity, one of the most important aspects in urban planning and earthquake design, is to establish for different ground motions the variation of spectral shapes with local site conditions. It is the main purpose of this investigation to suggest a simplified procedure for computing both, normalized acceleration spectral shapes and the dynamic site-period of soil deposits at the recording station directly from the recorded spectral shapes. The procedure incorporates the influence of type of soil and distance from caustive fault, showing a very acceptable degree of accuracy when compared to results obtained from expensive field surveys and dynamic soil analyses.

1 INTRODUCTION

For structural design purposes, several atempts have been made to establish the relationship between the general characteristics of recorded spectral shapes and the local soil conditions at the recording stations, showing that in spite of the differences in records used, the spectral shapes are in fact site-dependent, Seed, Ugas and Lysmer (1974), Alonso and Urbina (1978), etc. Spectral shapes are in fact quite complicated to anticipate since they vary, not only as a function of the local type of soil, but also as a function of other important parameters, such as the geometry of the deposit (see Fig. 6), the - distance from zone of energy release, stiffness of soil deposit at the recording station source mechanism, duration of ground motion, among others.

During earthquakes resonance of the ground occurs when the natural period of the soil deposit equals or approaches one of the fundamental periods of the bedrock motion (see Elton and Martin II, 1989). When this happens ground motions and structural damage is greatly amplified. Seed and Alonso (1974) concluded that in the 1967 Caracas earthquake, quasiresonance between tha underlying soil and the building itself provided the best explanation for otherwise puzzling damage patterns that were observed, concluding that high or low damage occurs if the structure has a natural period similar or dissimilar to it´s site´s period, i.e., the period at which the soil deposit resonates under earthquake excitation. Since the site´s period is not constant for a given soil profile as shown by Alonso and Larotta (1977) and others, but rather changes with the amplitude of the earthquake´s ground motion, from now-on we will denote it as the dynamic site-period Ts.

2 A NEW APROACH

For this investigation it was decided to classify soils into two major groups.

1. Group A: Soft to medium stiff clay deposits.
2. Group B: Rock sites, stiff soil sites (less than 50 meters deep), and deep cohesioless soil sites (greater than 75 meters deep).

Response spectral shapes, usually defined - as absolute acceleration response spectra divided by the maximum ground peak acceleration, represent a convenient way of defining the seismic reponse at a site. Based on the shapes of the 104 records used by Seed, Ugas and Lysmer (1974), on data obtained from recent earthquakes, and also, on analytical soil-response studies performed at different sites in Venezuela and elsewhere, it has been found that the relative position of the period at which maximum spectral acceleration takes - place, (so-called predominant period Tp), varies as a function of Ts, and D, in soils of group B, whereas for soils of group A, Tp - varies only as function of distance D. In this paper, a simple graphical method is proposed to serve as a tool for:

1. Anticipating normalized acceleration

spectra (only for λ=5%) for the two groups of soils herein considered, when Ts, D and the type of soil are known parameters, and

2. Evaluating directly from any given recorded spectral shape, the dynamic site-period of the deposit at the recording station, when the type of soil and the distance D, are known

Figure 1 and tables I and II provide the basic tools for such evaluations.

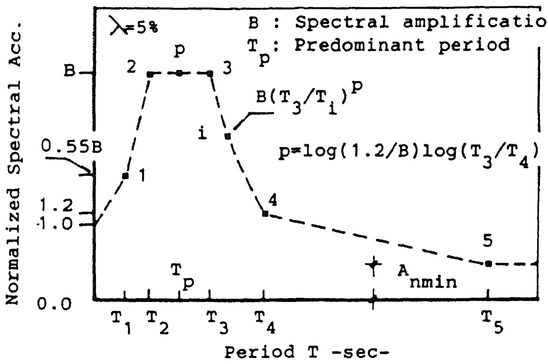


Figure 1. Proposed basic normalized acceleration shape.

Table I

Group	Soil	$\bar{T}_1$	$\bar{T}_2$	$\bar{T}_p$	B	Anmin
A	Soft	0.27	0.32	0.39	B*	0.40
B	rock	0.16	0.28	0.39	2.6	0.25
B	stiff	0.16	0.28	0.39	2.6	0.35
B	Deep c.	0.16	0.28	0.39	2.6	0.40

Where $$B^* = 2.6 + (.0032)D \qquad (1)$$

Table II

i	T_i		i	T_i
1	$F_s\bar{T}_1$		3	$2T_p - T_2$
2	$F_s\bar{T}_2$	and,	4	$1.5T_3$
p	$F_s\bar{T}_p$		5	$2.5T_4$

For both groups of soils A and B, the retive position of the so-called predominant period Tp is governed by a new parameter, the shift factor Fs, which has no units and has been defined in this investigation by the equation 2 in which $\bar{T}$p is equal to 0.39 (see table I).

$$F_s = T_p/\bar{T}_p \qquad (2)$$

Figures 2 and 3 show the variation of the predominant period T_p with distance to the causative fault proposed in this paper for soils of group A and B.

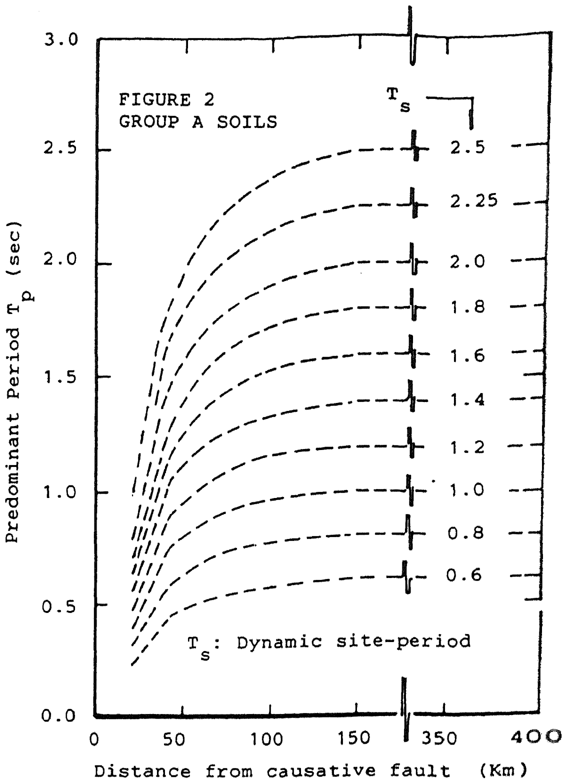


FIGURE 2
GROUP A SOILS

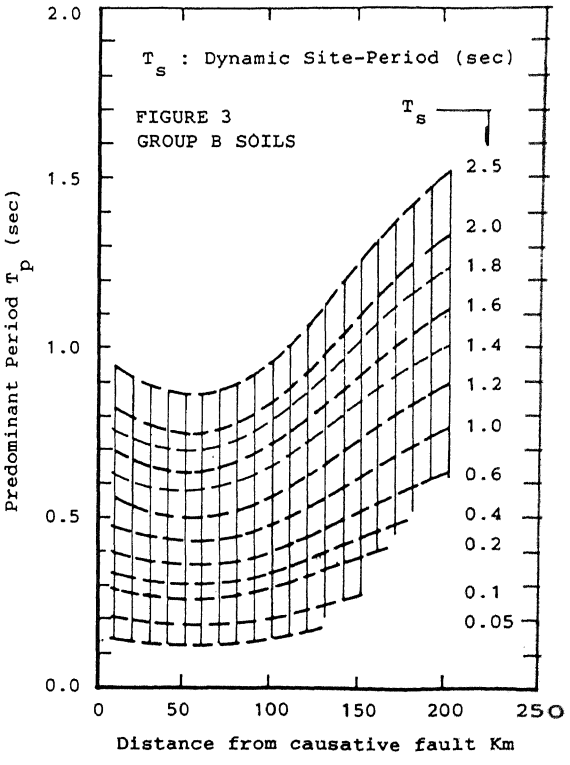


FIGURE 3
GROUP B SOILS

3. POTENTIAL USES OF PROPOSED METHOD

The information presented in Figs.2 and 3 can be readily incorporated to the process of seismic microzonation of a city. In effect, with the aid of such graphs, the evaluation of the dynamic site-period of a soil deposit by means of this technique, would be particularly useful in the event that a city, on which a net of strong motion accelerographs are already installed, were hit by an earthquake. In this case, it would be possible, directly from the recorded acceleration response spectrum, to detect within the city, soil deposits of different depths and/ or stiffnesses, simply by comparing the so-evaluated periods at the recording stations. The only information needed is the distance D from the zone of energy release, the type of soil (A or B in our discussion) and the predominant period Tp.

From Figure 2 it is readily apparent that for soils of group A the dynamic site-period Ts is virtually equal to the value of the predominant period Tp for distances greater than 130 km. To illustrate the simplicity of the method let us solve the following example.

Example: For the E-W acceleration response spectrum recorded at Foster City during the 1989 Loma Prieta earthquake shown in Fig.4 find the corresponding dynamic site-period T_s and draw the resulting spectral shape.

Solution: According to Idriss (1990), the soil deposit at the recording station is soft (group A), the epicentral distance 48 km and the predominant period is aproximately equal to 0.67 sec. With this information, T_s=0.86 sec directly from curves in Fig.2. The shift factor F_s can be then evaluated from equation 2, i.e.,

$$F_s=T_p/\bar{T}_p=0.67/0.39=1.72$$

By using the relationships shown in table II, and with the aid of Fig.1 for example we get

$$T_2=F_s\bar{T}_2=1.72\times0.32=0.55 \text{ sec}$$

$$T_3=2T_p-T_2=2\times0.67-0.55=0.79 \text{ sec}$$

$$B=2.6+0.0032\times48=2.754$$

and so on. The resulting spectral shape (dashed line) is shown in Fig. 4

4. COMPUTATIONS AND RESULTS

An extensive set of examples (see figures 4 to 11) are included showing a comparison of recently recorded acc. spectral shapes -vs- the anticipated ones obtained (by using the proposed technique) at sites with different soil conditions. Also the dynamic site-periods of the deposits were evaluated. In all cases a quite acceptable accuracy was obtained.

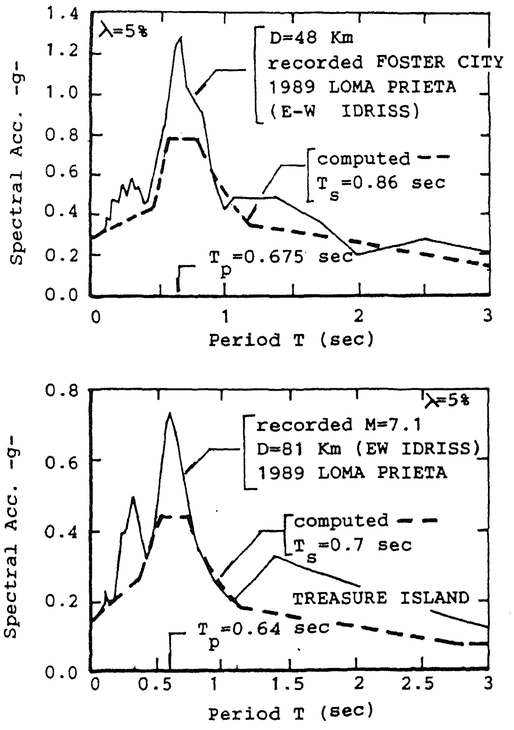


Figure 4. Acceleration response spectrum at different sites (1989 Loma Prieta EQ. Idriss (1990)).

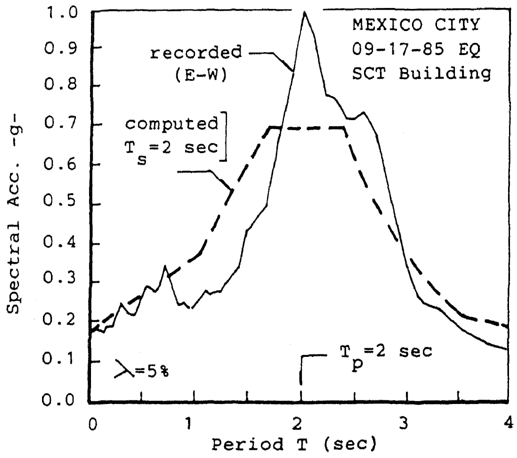


Figure 5. Acceleration response spectrum recorded at SCT Building (1985 Mexico EQ.)

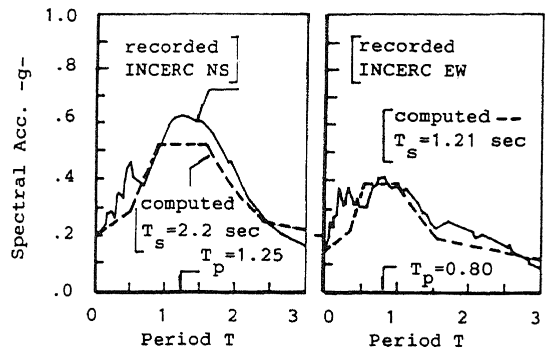
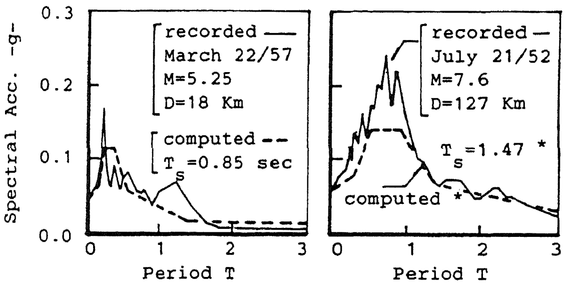


Figure 6. Influence of deposit geometry on spectral shapes (1977 Rumania EQ.)



S.Pacific Bldg.
San Francisco
(Soft soil)

Kern County Cal. EQ
Pasadena
(Deep cohesionless)

Figure 7 . Acceleration response spectra and dynamic site-periods evaluated for two ground motions with comparable maximum accelerations

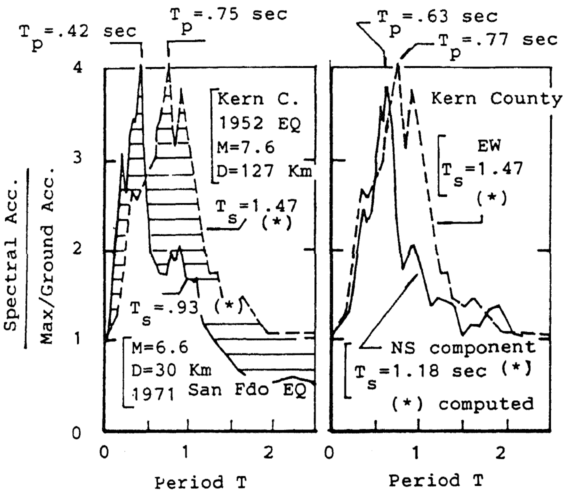


Figure 8. Influence of deposit geometry, magnitude and distance on spectral shapes (Caltech-Pasadena).

For engineering purposes it is often convenient and conservative to represent, for all available normalized spectra recorded or analitically computed, mean or mean + 1 standard deviation spectral shapes that can be properly combined for the four different soil conditions previously discussed (groups A and B). Figure 9, shows the results of such an study here performed for each type of soil and for variable distances and ranges of dynamic site-periods. From the smoothed response spectra shown in figure 9 it was decided (see figure 10) to reclassify the soils into the following four categories; S_1*: rock and stiff soils; S_2: deep cohesionless soils; S_3: soft to medium stiff clays and sands when $D \leq 130$ km., and S_4: soft to medium stiff clays and sands when $130 \leq D \leq 350$ km.

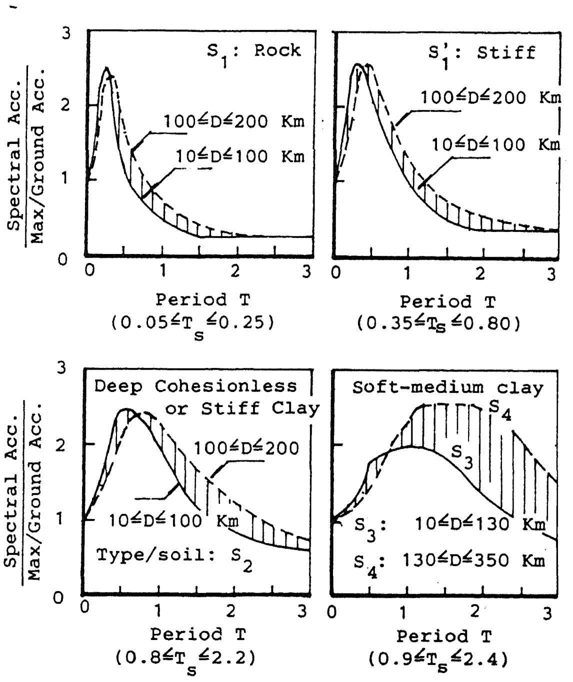


Figure 9. Average acceleration spectra for different site conditions.

5. CONCLUSIONS

The preceding pages have emphasized the importance of local soil conditions on the shape of the response spectrum. Some of the most - important conclusions are listed bellow:

1. Spectral shapes of soils depend primarly on the dynamic site-period of the soil deposit T_s at the recording station, and also on the distance D from the zone of energy release. It was also found that the range of - periods at which maximum spectral acceleration takes place (so-called predominant period range T_p), varies as a function of T_s and D.

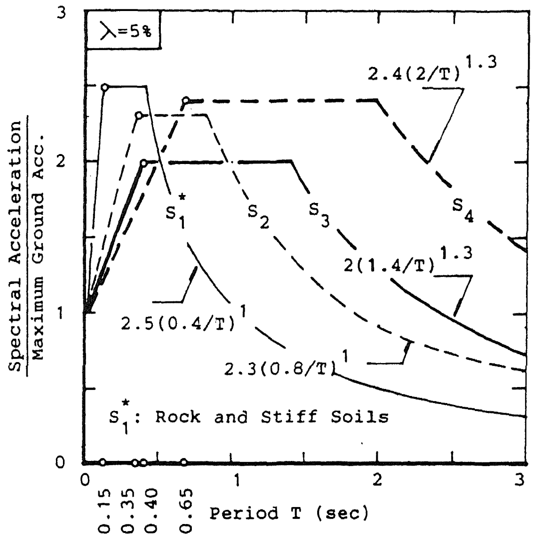


Figure 10. Normalized curves proposed for use in building code.

2. For soft soils only, it is shown that for distances greater than 130 km, the dynamic site-period T_s is virtually equal to the predominant period T_p, i.e., $T_s \simeq T_p$.

3. The maximum peak ground acceleration does not seem to have a determinant effect on the dynamic site-periods (see figure 7).

4. The influence of deposit geometry seems to be a very important parameter which greatly affects the spectral shapes and the dynamic site-periods, as is clearly shown in figures 6 and 8.

5. The dynamic site-period is not a constant for a given soil profile (see left side of figure 8). It changes with the excitation because of the non-linear behavior of soil modulus with increasing strain.

6. We can not think of an easier technique to evaluate the dynamic site-period directly from the recorded acceleration spectrum that the one presented in this investigation, which in our opinion provides the engineer with results that are quite acceptable for engineering practical purposes. Please do not forget this is an empirical method and by no means pretends to be a substitute of dynamic analysis such as SHAKE.

6. FINAL REMARKS

The influence of soil conditions on the forms of response spectra is also illustrated by the series of six response spectra shown in figure 11, (Seed and Idriss, 1969) four of which were obtained from motions recorded in the same city in the same earthquake. Also shown in the figure are the soil conditions at the sites, the dynamic site-periods and the smoothed spectral shapes evaluated with the aid of figures 1, 2, 3 and tables I and II. (see dashed lines). The spectra are arranged in sequence from A to F, corresponding to increasing degrees of softness of the soil conditions underlying the recording stations.

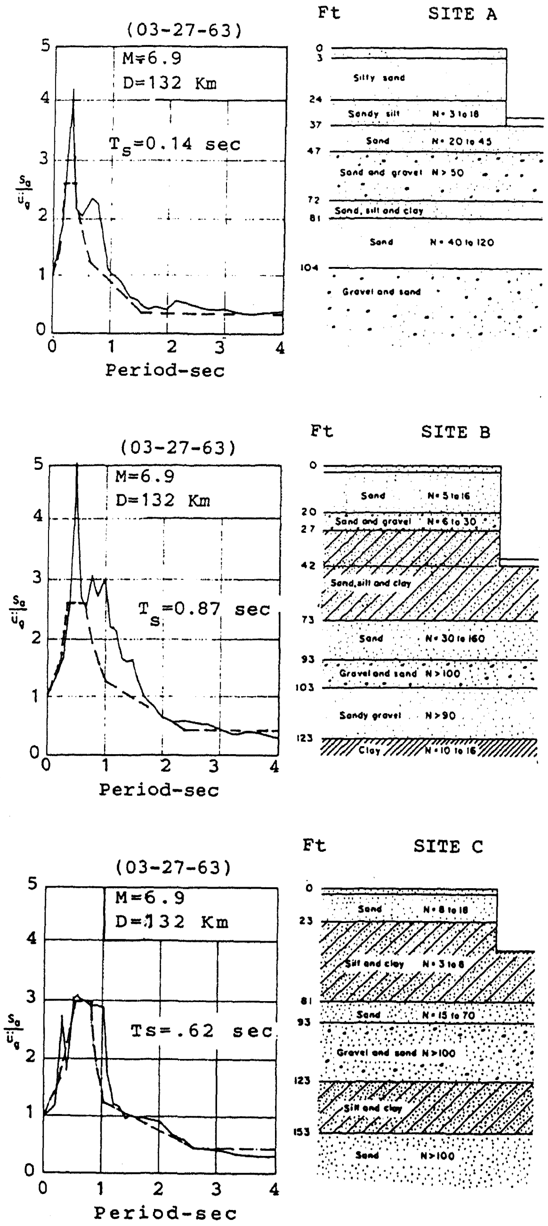


Figure 11a. Influence of soil conditions on form of response spectra. Dynamic site-periods (sites A to C).

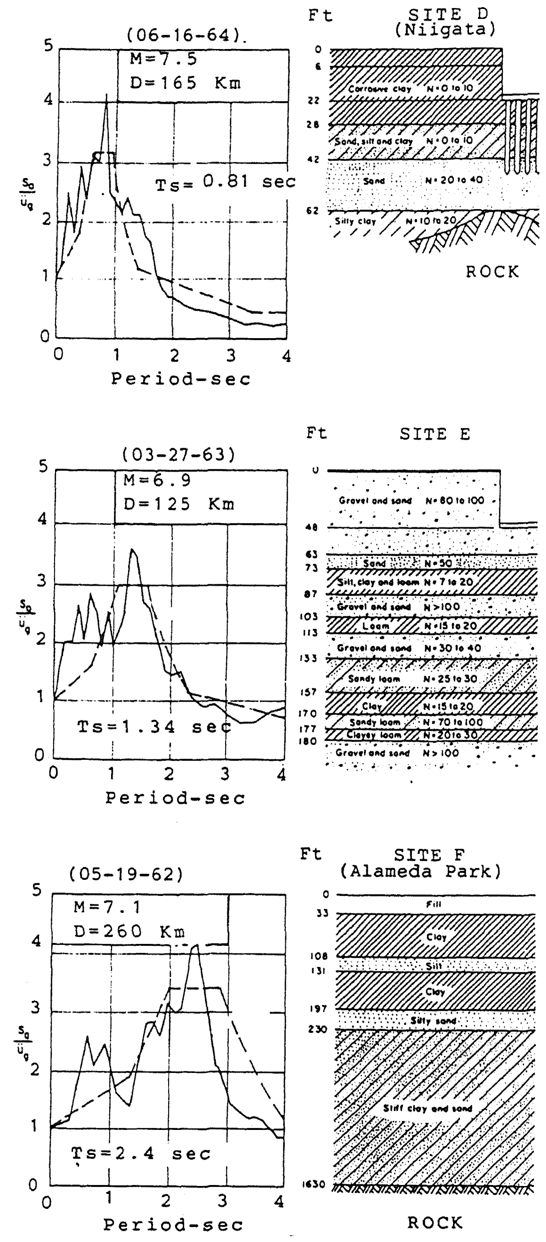


Figure 11b. Influence of soil conditions on form of response spectra. (Sites D to F).

Finally, it should be mention that for any dynamic site-period ($0.10 \leq T_s \leq 2.5$ sec), the curves shown in figures 2 and 3 can be readily obtained if the T_p values for $T_s=1$ sec are multiplied by the factors f_A and f_B shown in figure 12 , as seen in equations (3) and (4):

$$T_p=0.952f_A \text{ (group A)} \qquad (3)$$

$$T_p=0.473f_B \text{ (group B)} \qquad (4)$$

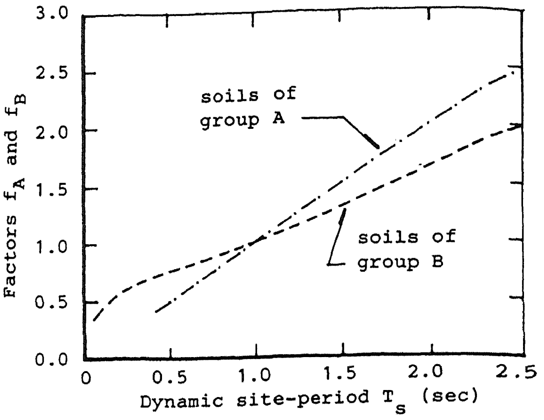


Figure 12. Variation of factors f_A and f_B with the dynamic site-period.

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