SEISMIC MICROZONATION OF TOKYO AREA

by

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SUMMARY

In this paper, seismic microzonation maps of the principal area of Tokyo are made in terms of fundamental period of soil deposit, maximum response acceleration of ground surface.

The features of the present method are as follows;
(1) Soil layer, N-value of which is larger than 50, is regarded as the base layer for analytical model of soil deposit. (2) Simulated earthquake ground motions are made use of as input at the base layer. (3) Nonlinear stress-strain relationship of soils is taken into account.

INTRODUCTION

As is well-known, the damage of structures during earthquake strongly depends on the local soil conditions. In the present Japanese Building Code, soil conditions of three types are defined with respect to geological, topographical and mechanical properties of soils and the design seismic load is determined by considering the dynamic characteristics of superstructure and underlying soil deposit.

It is strongly requested, therefore, to prepare the seismic microzonation maps, which show the horizontal changes of soil condition in the specified region, primarily for aseismic design purposes, secondarily for the effective land utilization and seismic disaster prevention.

In this paper, seismic microzonation maps of the principal area of Tokyo, Japan are made in terms of fundamental period of soil deposit, maximum response acceleration at the ground surface.

METHODOLOGIES

In Tokyo, the capital of Japan, many kinds of buildings, public works such as bridges and highways, have been constructed. Thereby, a great deal of bore-hole records are obtained. To represent the microzonation maps, the methodologies for the arrangement of these bore-hole records, dynamic analyses of soil deposits and presentation techniques of the analytical results should be established at first.

Arrangement of Bore-Hole Records

The data on soil conditions commonly available in Japan are bore-hole records. It is assumed, at first, that only bore-hole records can be utilized to estimate the soil conditions at any sites.

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The informations on soil conditions obtained from bore-hole test results are, in general, thicknesses, soil types such as clay and sand etc. and N-values from the standard penetration tests. Boring stations are plotted on the topographical map of 1/25000-scale published by the Geographical Survey Institute, Ministry of Construction. The dimension of the area presented in a 1/25000-scale topographical map is fixed to be 7'30" and 5' in the longitudinal and latitudinal directions, respectively.

A 1/25000-scale topographical map is subdivided into 600 blocks, i.e., 20 divisions in N-S direction, 30 divisions in E-W direction. The elemental block thus subdivided is 15"x15", i.e., approximately 470m(N-S) x 370m(E-W) rectangle. The adoption of the block size is due to, (1) Uniform subdivision, even for another area in Japan, is possible by the application of longitude and latitude. (2) not too large to avoid the excessive change of soil condition in an elementary block. The objective area, Tokyo, is divided into 2000 blocks as shown in Fig. 1.

Fig. 2 shows the location of boring stations of records collected in the present study. Although the largest number of bore-hole records are obtained in this area in Japan, a number of blocks without a single record are found.

Conversion of Original Soil Profiles into Analytical Model

Though the distribution of bore-hole records in each block is not uniform, the soil condition in the block is determined by using the most pertinent bore-hole record, which satisfies the following criteria. (1) A soil profile reaching to the firm soil layer such as Tokyo Sandy Gravel Layer. (2) A soil profile reaching to the layer stiff enough to be regarded as base layer in response analyses, e.g., a layer with N-value more than 50.

Simplification of Soil Profile

Soil profile thus chosen in each block is simplified according to the method proposed in Ref. 1., applying the concept of soil type factors (hereafter denoted by STF) and N-values. The simplification is made by applying the additional STF's to the original definitions. The STF's newly utilized are 7/6 for gravelly sand, 4/3 for sandy gravel, 3/2 for gravel and 2 for rock, in addition to the original definition, i.e., 0 for clay, 1/3 for sandy clay, 2/3 for clayey sand and 1 for sand as shown in Fig. 3.

The simplification procedure by STF is summarized as follows;
Interface is laid, when the difference of STF's of two consecutive sublayers exceeds 0.45 for layer with STF less than 1.0, 0.25 for layer with STF larger than 1.0. Otherwise, adjacent sublayers are regarded as a single layer. The simplification process by N-values is same as the original one.

New STF of the simplified layer is determined by taking the geometric average of STF's weighted by thicknesses of initial sublayers within the new layer. N-value for the new layer is determined by taking the simple average for the initial sublayer in the range from 1 to 99. An example of simplification is shown in Fig. 4.

Determination of Dynamic Characteristics of Simplified Layers

The dynamic characteristics of soils of constituting sublayers are determined in the next step. The unit weight of soil generally depends on the soil type, the extent of compaction, etc. In this paper, the unit weight is automatically determined by use of STF with the assumption that unit weights of clayey soil (STF=0) and sandy soil (STF=1) are 1.50 and 1.85 ton/m^3, respectively as shown in Fig. 5. The unit weight of soil having the STF more than 1 is determined by extrapolation.

The initial shear modulus is related with the shear wave velocity as,

$$G_0 = \rho V_s^2 \qquad (1)$$

where G_0 : initial shear modulus (ton/m^2)
ρ : mass density of soil (ton$\cdot$sec^2/m^4)
V_s : shear wave velocity (m/sec)

However, in general, the observation of shear wave velocities are rarely made, even in the construction sites. Therefore, the following empirical relationship between dynamic shear modulus and N-value is employed. (Ref. 2)

$$G_0 = 1200 \cdot N^{0.8} \qquad (2)$$

It is also recognized that shear modulus and damping factor of soils are strain-dependent. The dynamic nonlinear model between shear strain and shear stress employed in this analysis is as follows; (Ref. 3)

$$u = \frac{v}{G_0}\{1 + a\left|\frac{v}{Su}\right|^b\} \qquad (3)$$

where u : shear strain
v : shear stress
G_0 : initial shear modulus
Su : shear strength
a = $(G_0/Su)\cdot 0.01 - 1.0$
b : constant ; b = 1.4 for clay
b = 1.6 for sand

The shear strength of clayey soil is approximately proportional to the shear modulus G_0, henceforth, the ratio G_0/Su for clayey soil is herein set to be 600, and the ratio G_0/Su for sandy soil is conveniently set to be 1100. Ratios G_0/Su for soil types other than the above-mentioned two soil types are determined according to the STF's as well as the determination of unit weights of soils.

When this nonlinear shear stress-strain model is used, the strain-dependencies of shear modulus and equivalent damping factor are shown in Fig. 6 and Fig. 7, respectively.

The damping of Rayleigh type other than the above-mentioned hysteretic type is additionally given assuming 2 percent both for the first and the second modes of the analytical model.

Input Earthquake Ground Motion at Base Layer

In order to make a practical regional seismic risk map intended herein, it is desirable to use an earthquake ground motion recorded in Tokyo area with an adequate intensity as an input motion at the base layer.

However, no earthquake accelerogram called as a strong ground motion has been recorded in this area since the beginning of strong ground motion observation in Japan. It is appropriate, therefore, to make use of some simulated earthquake accelerogram instead of the observed one.

The earthquake time history adopted as an input motion at the base layer

is generated so as to possess the following characteristics,
(1) Fourier spectrum of the time history is uniform or constant within the frequency range between 0 and 10Hz. This specification satisfies our practical interest on the earthquake response of ordinary buildings for clarifying response properties of soil deposits above the base layer, free from the consideration of an influence of frequency characteristics of the input ground motion. (2) Phase content of Fourier transform is uniformly distributed between 0 and 2π. (3) Intensity function, which provides an envelope curve of time history, is chosen for the motion to possess a realistic shape. (4) Average level of frequency content is determined so that the average of maximum amplitudes of 100 generated sample waves becomes 100 gal. (5) Among the 100 sample waves, the time history, the maximum acceleration of which is the nearest to the average value, i.e., 100 gal, is chosen as an input motion at the base layer.

The time history thus generated is shown in Fig. 8 together with its Fourier spectrum. The triplicated time history is also used as the severer input motion. The surface responses are to be computed for any blocks in which more than one bore-hole record is collected. The total number of blocks amounts to 946.

Response Analyses of Soil Layers

In the present study, horizontally layered model for soil deposits is used to compute the surface responses. Surface response of soil deposit subjected to the input earthquake motion is computed by the direct integration method, evaluating the shear modulus of each layer at each computation time step according to the induced shear strain, by use of the aforementioned nonlinear model of soils. The equation of motion for multi-degree of freedom system is solved by theta-method proposed in Ref. 4.

Since the fixed supporting condition of layered model is used, the radiation damping is not taken into account.

SEISMIC MICROZONATION MAPS

The microzonation map in terms of fundamental period T_G of soil deposit, i.e., the longest natural period of the analytical model of soil deposit is shown in Fig. 9, by use of the initial shear moduli.

Classification of fundamental periods is made as follows;

(1) $0.00 < T_G \leq 0.20$ (2) $0.20 < T_G \leq 0.35$ (3) $0.35 < T_G \leq 0.55$
(4) $0.55 < T_G \leq 0.75$ (5) $0.75 < T_G \leq 1.00$ (6) $1.00 < T_G$

The above classification is related with the soil classification stated in the present Japanese Building Code, i.e., Class (1), Class (2)+(3)+(4) and Class (5)+(6) correspond to the soil deposits of the first, second and third kinds, respectively.

The east side of Tokyo area, e.g., Kohtou and Edogawa wards, as seen in the right side in Fig. 9, is an area of extremely soft soil, the approximate fundamental period around the area is longer than 0.75 second, corresponding to the soil deposits of the third kind. On the other hand, the western part of Tokyo area, as seen in the left side in Fig. 9, is an area of comparatively stiff soil, called "Yamanote" in Tokyo, corresponding to the soil deposits of the second kind. The soil deposit of the first kind is rarely found in the objective area.

In Fig. 10, the microzonation map for the computed maximum response acceleration A_{max} in gal at the ground surface is shown by using the following classification,

(1) $A_{max} > 200$ (2) $200 \geqq A_{max} > 150$ (3) $150 \geqq A_{max} > 100$
(4) $100 \geqq A_{max} > 50$ (5) $50 \geqq A_{max}$

In the western part of Tokyo, there are many blocks having the amplification ratios of 1.5 to 2.5 between the maximum accelerations of surface and base layers, but in the eastern part of Tokyo, there are many blocks in which the amplification ratios do not exceed 1.

Fig. 11 shows the relation between the fundamental period of the ground and maximum surface acceleration obtained from the analytical results for "Tokyo Shubu". From the regression analysis the following empirical equation is obtained.

$$A_{max} = 78.5 \cdot T_G^{-0.846} \qquad (4)$$

In Fig. 12, the microzonation map for the computed maximum surface acceleration, when soil deposits are subjected to the triplicated input motion, i.e., maximum acceleration is 300 gal.

Classification is also made so that the amplification ratio is same as the previous case. It is seen from Fig.12 that in most of the eastern part of Tokyo, the level of surface acceleration is less than that of the input level and there are many blocks having the amplification ratios less than 0.5. Similarily, regression analysis shows as follows. (Fig. 13)

$$A_{max} = 139 \cdot T_G^{-0.955} \qquad (5)$$

Comparing those figures, it is clear that the amplification ratio of maximum acceleration is reduced as the intensity of input motion increases.

The regressive curves for two input motions by all the computation results in the objective area are as follows.

$$\left.\begin{aligned} A_{max} &= 78.2 \cdot T_G^{-0.767} \quad \text{for 100 gal input} \\ A_{max} &= 142.1 \cdot T_G^{-0.874} \quad \text{for 300 gal input} \end{aligned}\right\} \qquad (6)$$

CONCLUSIONS

It may be pointed out that the above equations are valid for the input motion shown in Fig. 8. Therefore, the coefficients in the above equations will slightly change, when the input motion is replaced with another time history. But the tendencies shown in this paper become the basic characteristics of the responses of soil deposits to estimate the surface ground motion during earthquakes in Tokyo area.

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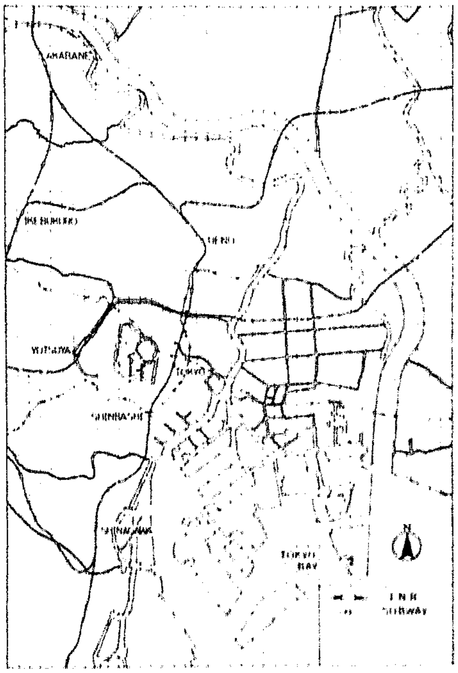

Fig. 1 Objective Area (Tokyo)

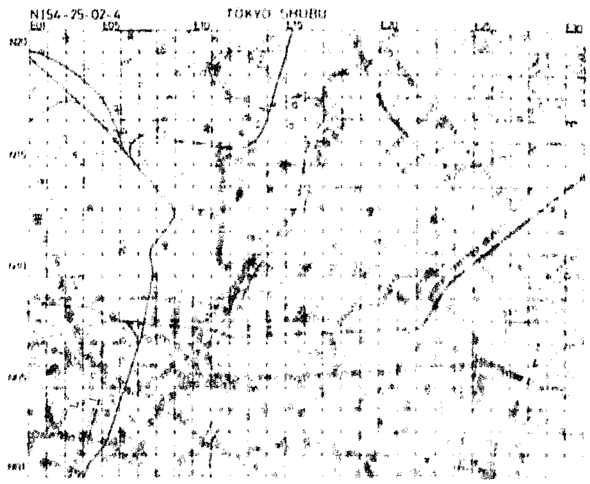

Fig. 2 Location of Boring Station

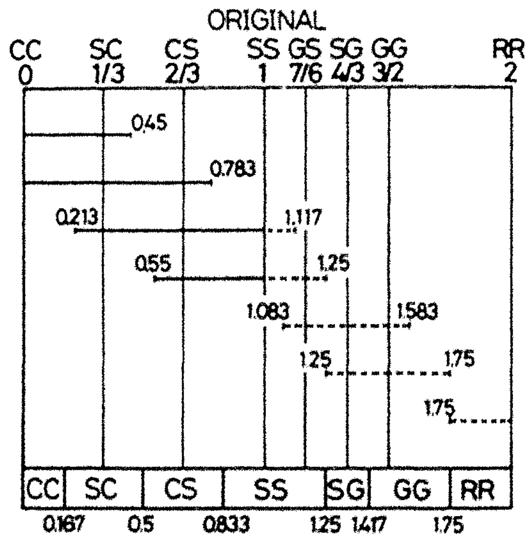

Fig. 3 Definition of STF's

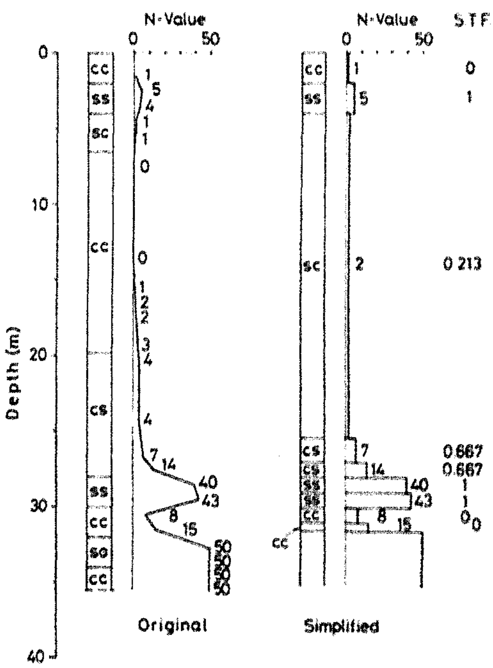

Fig. 4 An Example of Simplification

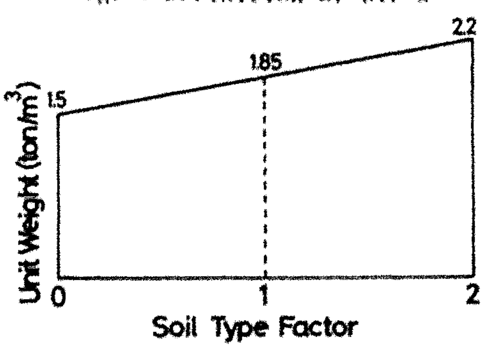

Fig. 5 Determination of Unit Weight

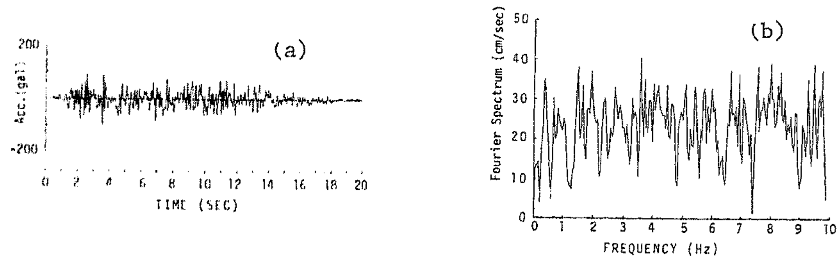

Fig. 8 Input Earthquake Motion and the Fourier Spectrum
(a) Input Earthquake Motion
(b) Fourier Spectrum

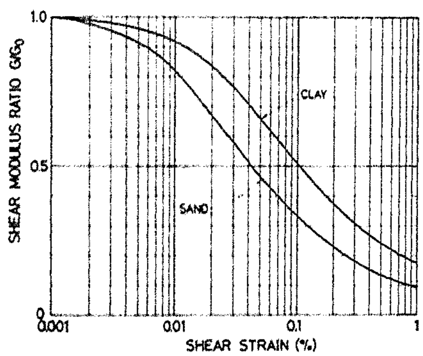

Fig. 6 Relationship between Shear Modulus and Shear Strain for Clay and Sand

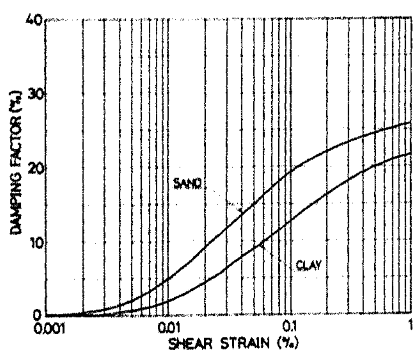

Fig. 7 Relationship between Damping Factor and Shear Strain for Clay and Sand

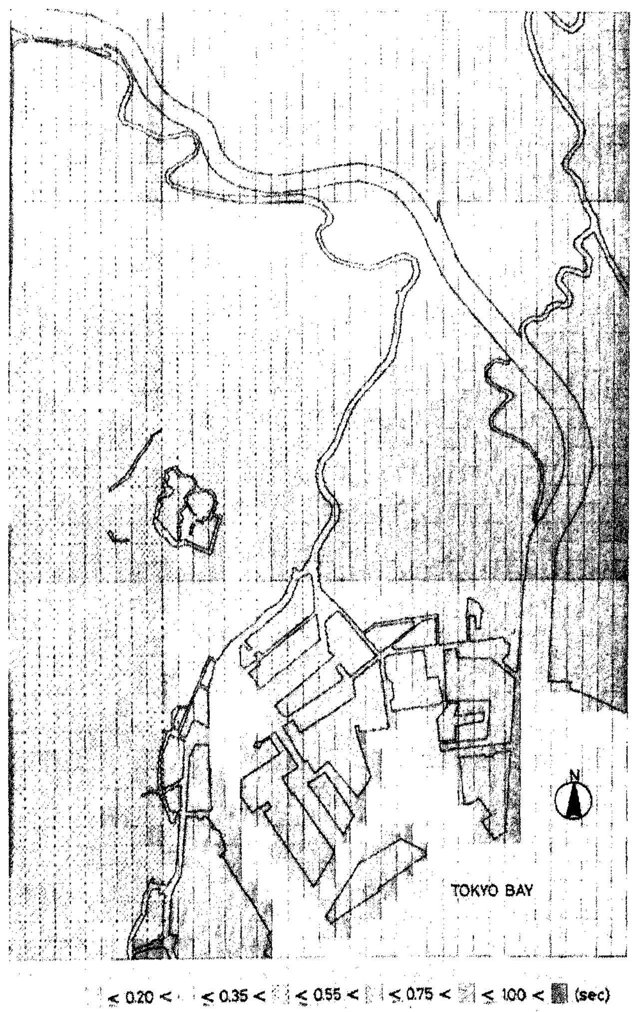

Fig. 9 Fundamental Periods of Soils

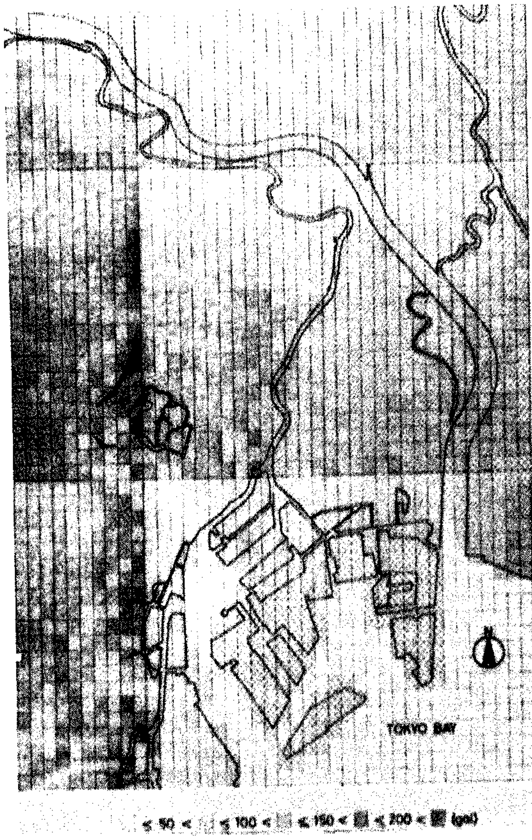

Fig. 10 Max. Surface Acceleration for 100 gal Input Motion

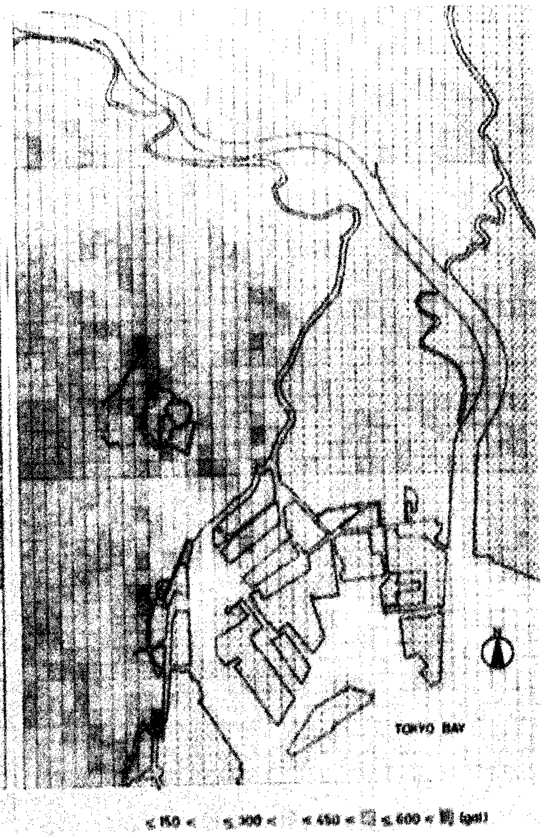

Fig. 12 Max. Surface Acceleration for 300 gal Input Motion

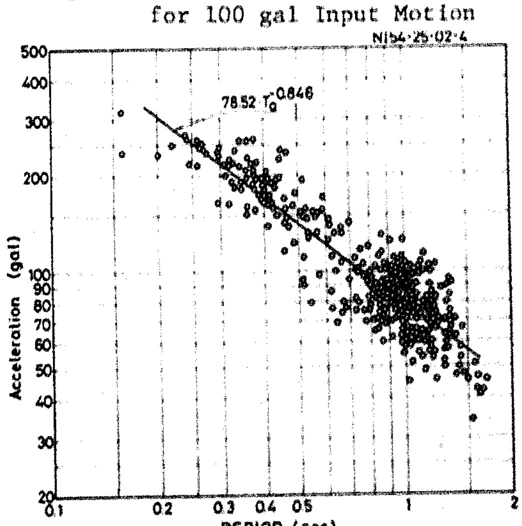

Fig. 11 Relationship between Amax and T_G for 100 gal Input Motion

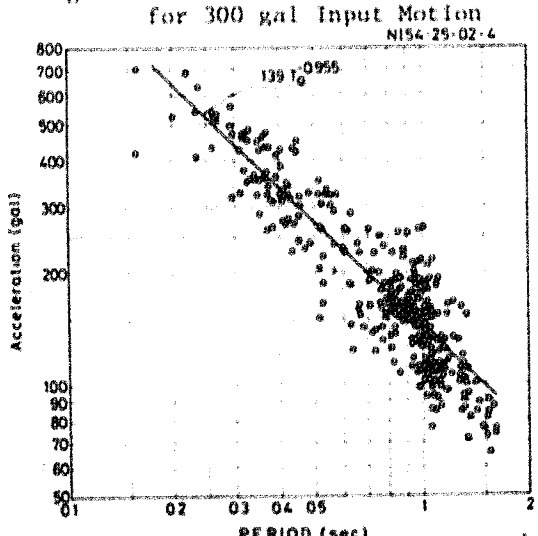

Fig. 13 Relationship between Amax and T_G for 100 gal Input Motion