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Evaluation of liquefaction due to surface wave prospecting and its application

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ABSTRACT: The present paper proposes an evaluation method of soil liquefaction. In the proposed method, we compare the observed S wave velocity(V_s) of the ground with the critical S wave velocity(V_{scr}), which is such S wave velocity as the FL-value in FL-equation comes to be 1.0. $V_{scr}>V_s$ means occurrence of liquefaction and $V_{scr}<V_s$ signifies no occurrence of liquefaction . Rayleigh waves generated by a vibrator on the ground are used to get S wave velocity(V_s) of the ground. The liquefaction risk, which means the extent of liquefaction potential and is classified into three ranks, were consistent with the survey on liquefaction due to past earthquakes. We can say , therefore, that the present method is useful for evaluation of liquefaction and available for microzoning on liquefaction for the areas which may be attacked by a big earthquake in the future.

1. INTRODUCTION

In the present paper, the liquefaction potential means the latent possibility of occurrence of liquefaction at the site concerned. The liquefaction risk signifies the extent of liquefaction potential and is classified into such rank as rank 1(heavy to moderate), rank 2(slight) and so forth. The extent of liquefaction and its damages seem to change from point to point very finely even in small areas. This implies that evaluation of liquefaction potential for the coming earthquake should be done as densely as possible.

For evaluation of liquefaction potential at some sites, it is essential to know the geological and geotechnical conditions of the ground , which ought to include the kind or age of soils and distributions of S wave velocity , density and so on. So far the geological and geotechnical data by borehole survey have been utilized to evaluate liquefaction . However, as making boreholes is fairly expensive , it is difficult to achieve evaluation of liquefaction for lots of points in small area.

Meanwhile , seismic prospecting, especially surface wave prospecting which uses Rayleigh wave is very convenient for determining underground structure of S wave velocity, because it is fairly simple and not expensive . Therefore, it seems to be reasonable to conbine the data due to borehole survey and surface wave prospecting for evaluating liquefaction as in detail as possible.

2. LIQUEFACTION POTENTIAL AND LIQUEFACTION RISK

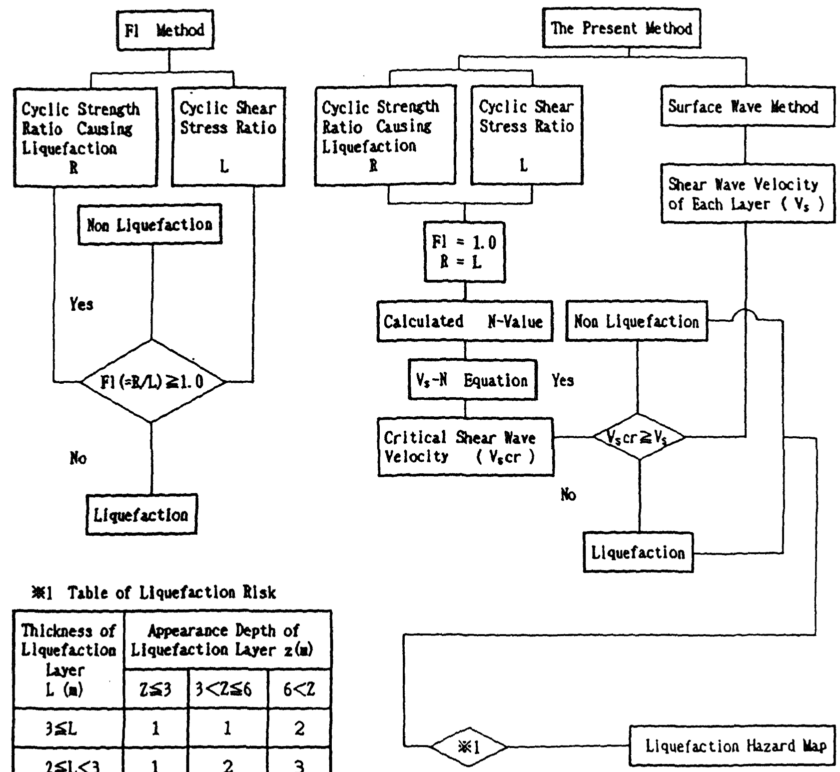
What is called FL-method for evaluation of liquefaction potential uses N-values by penetrating test of boreholes. The present methoid , on the other hand, compares S wave velocity of the ground(V_s) with the critical S wave velocity(V_{scr}) which is equivalent to such critical N-value(N_{cr}) as the FL-value in FL equation comes to be 1.0. N-values are measured in boreholes. Meanwhile, as S wave velocity(V_s) can be measured by surface wave prospecting which uses Rayleigh wave generated by a vibrator on the ground , it is needless to drill boreholes. Therefore, it is favorable to use the critical S wave velocity(V_{scr}) in return for the critical N-value(N_{cr}) from practical points of view.

2-1. Evaluation of liquefaction potential by critical S wave velocity and ranking of liquefaction risk

The FL equation is shown by the following .

$$FL=R/L$$

(R:dynamic shear strength ratio



※1 Table of Liquefaction Risk

Thickness of Liquefaction Layer L (m)	Appearance Depth of Liquefaction Layer z(m)		
	Z≦3	3<Z≦6	6<Z
3≦L	1	1	2
2≦L<3	1	2	3
1≦L<3	2	3	3
0≦L<1	3	3	4

Risk 1 : High
2 : Moderate
3 : Low
4 : Non

Fig. 1 Flowchart for evaluation of liquefaction potential and ranking of liquefaction risk. Liquefaction potential is evaluated by comparing V_{scr} with V_s and ranking of liquefaction risk is made on the basis of thickness and depth of liquefied layer.

which includes N-value
L:seismic shear stress ratio which includes maximum acceleration on the ground)

FL=1.0 corresponds to the boundary to show whether or not liquefaction occurs . That is, FL-value>1.0 means occurrence of liquefaction and FL-value<1.0 signifies no occurrence of liquefaction.

FL=R/L=1.0 means that the dynamic shear strength ratio(R) equals to the seismic shear stress ratio(L). That is,

$$R=0.0882*\text{square root}(N/(e.f.+0.7))+R_2+R_3=L \quad (1)$$

From the above equation, the following is obtained.

$$N=(e.f.+0.7)*((L-R_2-R_3)/0.0882)^2 \quad (2)$$

(e.f.:effective stress, R_2:function of mean radius of grain of sand or soil, R_3:function of content ratio of fine grain)

The critical N -value(N_{cr}), which is N-value for FL=1.0 and is calculated from eq.(2), is converted to the critical S wave velocity (V_{scr}) by the relationship between N-value and S wave velocity(for example, Taniguchi(1989)). In order to calculate the critical N-value(N_{cr}), consequently the critical S wave velocity(V_{scr}), we need to make the model of underground structure which typifies the ground of the area concerned . That is, we have to make an

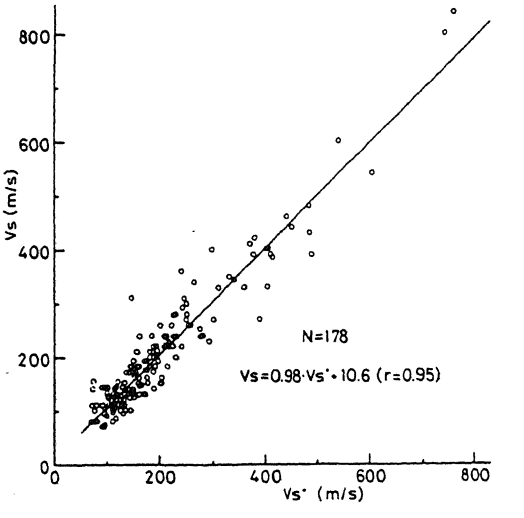


Fig. 2 Relation between S wave velocity by well-shooting method(V_s) and S wave velocity by surface wave prospecting(V_s^*).

estimate of mean radius of grain of sand or soil, density for each layer and level of ground water, for which the geological and geotechnical data due to borehole survey are used. The maximum acceleration on the ground is obtained by seismic hazard evaluation or response analysis.

As the results, liquefaction potential is evaluated as follows;

$V_{scr} > V_s$: Liquefactions occur.
$V_{scr} < V_s$: Liquefactions do not occur.

As described in the next section, the S wave velocity(V_s) is measured by surface wave prospecting.

Liquefaction risk, which means the extent of liquefaction potential, is evaluated on the basis of the thickness and depth of liquefied layer. In the present paper, liquefaction risk is classified into three ranks of 1(heavy to moderate), 2(slight) and 3(no liquefaction). Fig. 1 shows the flowchart for evaluation of liquefaction potential and ranking of liquefaction risk.

2-2. Determination of S wave velocity of the ground

In the present paper, surface wave prospecting is used to get S wave velocity(V_s) in the ground. Rayleigh waves of various frequencies are generated by a vibrator on the ground and the phase velocity (V_r) for each wave length (l) are measured. By comparing the phase velocity(V_r) with S wave velocity(V_s) determined by well shooting method, a linear relation between V_r and

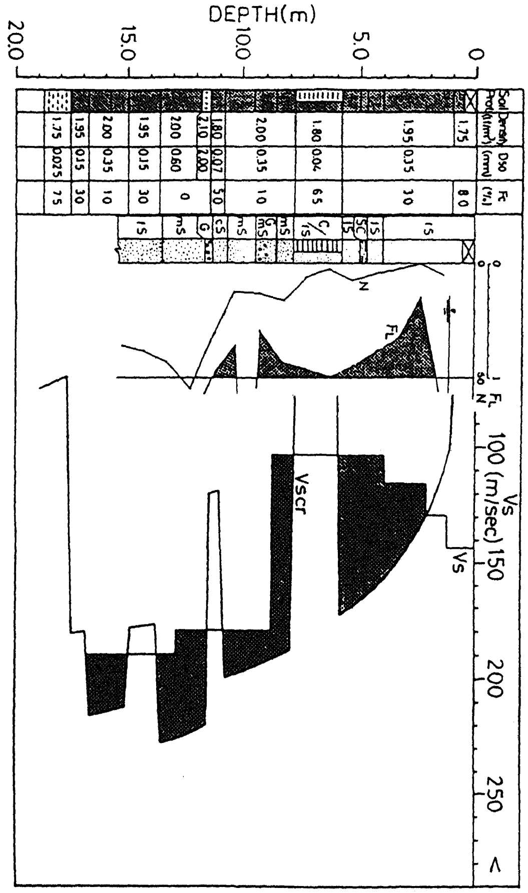
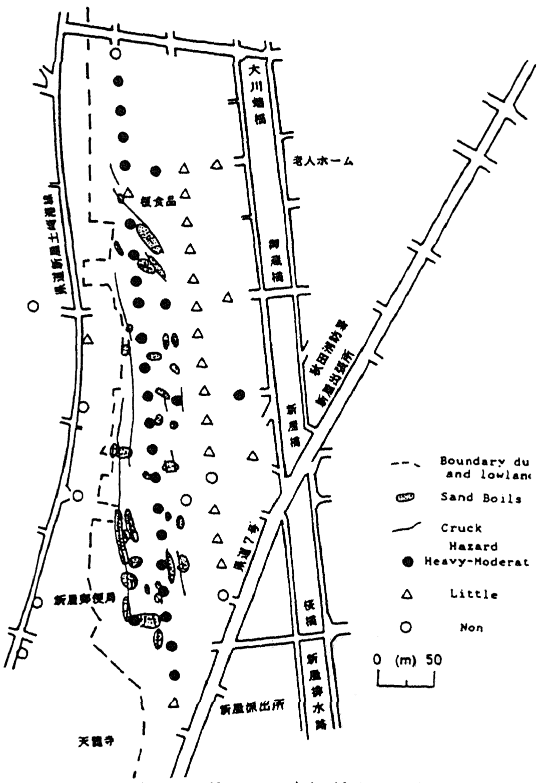


Fig. 3 Examples of evaluation of liquefaction potential due to the present method and the FL method for Araya-Motomachi. Both results are consistent each other.

V_s was obtained. This means that the underground structure of S wave velocity can be determined by surface wave prospecting.

In the following, the process to determine S wave velocity(V_s) by surface wave prospecting are shown. (1) On the assumption that Rayleigh waves propagate along the ground surface and penetrate into the depth (D) corresponding to the half wave length(l/2) in each frequency, the curves which relate V_r to l/2 are drawn. On the other hand, mean S wave velocity($\underline{V_s}$) are calculated from V_s in each layer which were obtained by well shooting method and the curve showing the relationship between mean velocity ($\underline{V_s}$) and depth(D) are obtained. The first curve coincided with the second one very well at many experimental sites. For example, the mean velocities $\underline{V_s}$ for the depth D=10m and 20m are shown as follows(Takaya et al. (1990)).



Araya-Motomachi, Akita city, Akita prefecture

Fig. 4 Liquefaction risk and liquefaction phenomena due to the past earthquakes. The sites of ranking 1(heavy to moderate) are located in and around the areas where liquefaction had been occurred by earthquakes.

$$V_s = 1.04V_r + 14.6 \quad (D=10m) \quad (3)$$

$$V_s = 1.05V_r + 7.7 \quad (D=20m) \quad (4)$$

(2) The S wave velocity(V_s*) of each layer are calculated by the relation between V_r and 1/2 and Dix's equation. The above V_s* ,which was determined by surface wave prospecting,has the following linear relation with V_s due to well shooting method (Fig. 2).

$$V_s^* = 0.98V_s + 10.6 \quad (5)$$

It is concluded that S wave velocity of the soft ground , if the values range from 80m/sec to 600m/sec , can be determined by surface wave prospecting.

3. EXAMPLES OF ANALYSIS AND CONCLUSIONS

The evaluation of liquefaction potential and ranking of liquefaction risk have been done for Araya-Motomachi area in Akita city and Shohnan area in Noshiro city , Akita prefecture which were attacked by Nihhonkai Chubu(central) earthquake(May 26,1983,M 7.7) and in Takasu area in Chiba city,Chiba prefecture where liquefaction phenomena were observed at the time of Chibaken-Thoho(east)-oki(offshore) earthquake(December 17,1987,M 6.7). Fig. 3 shows the analysis for Araya-Motomachi. The comparisons between the present results of liquefaction risk and the extent of liquefaction due to the past earthquake showed fairly good consistence(Akita prefecture(1984),Kitsunezaki(1984) and Tohno et al.(1985)) (Fig. 4).

The phenomena accompanied with an earthquake such as maximum acceleration on the ground ,liquefaction and others vary very finely from place to place because of variation of underground structure. In order to estimate the extent of liquefaction due to a coming earthquake ,minute investigations of shallow underground structure are required.The data of borehole survey give accurate informations on the underground ,but drilling boreholes are expensive and take much time. It is impossible ,therefore ,to get sufficient and accurate informations of the ground conditions for wide area such as one city . This is because we have developed the present method.

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