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Seismic response analysis of layered ground considering uncertainty of soil parameters

Toshikazu Ikemoto & Masaru Kitaura
Kanazawa University, Japan

Masato Tsurugi
Geo-Research Institute, Osaka Soil Test Laboratory, Japan

ABSTRACT : This paper deals with a new probabilistic approach for evaluating earthquake response of the layered ground and points out the effects of uncertainty in soil parameters on the response. The new method requires only two or three response functions for each variable. We examine the precision of the results obtained by this method, comparing those by Monte Carlo simulation. The method is applied to evaluating response of the ground with linear and equivalent linear stress-strain curves of soil. The results obtained by the method have quite good agreement with those by Monte Carlo simulation.

1 INTRODUCTION

In seismic response analysis of the layered ground, fixed values, e.g. mean values of soil parameters have been used. There is, however, essentially randomness in soil parameters of the ground, as well as errors in measuring them. Therefore, it is necessary to take into account such uncertainty in soil parameters in analyzing the seismic ground response. In this paper, we propose a new probabilistic approach in evaluating the response of the ground and point out effects of uncertainty in soil parameters on the seismic ground response.

In seismic response analysis of the ground, multiple reflection theory[1)] has been used. Therefore, our new analytical and probabilistic method incorporates point estimate method as well as the nonlinearity in stress-strain curves of soil in using the multiple reflection theory. Herein, a study is conducted to investigate precision in the method by comparing the results by Monte Carlo simulation. Using the proposed method, effect of uncertainty of soil parameters on linear and equivalent linear ground responses to earthquake is discussed.

2 APPROXIMATE METHODS

Although Monte Carlo simulation technique provides a straightforward means of analyzing complex mathematical models, it has still disadvantages such as a large number of trials required. The point estimates method, however, requires only two or three evaluations of a function for each variable considered, gives accuracy comparable to a second order Taylor's series analysis, and is applicable to non-analytical functions.

Figure 1 shows the shape of probability density and cumulative distribution functions of a soil parameter which is approximately normally distributed. A probability mass and its cumulative distribution functions for two and three point estimates are also shown.

Approximate methods have been developed as a means of estimating the moments of a function $y(x)$. Such methods are used in case that only the moments of $y(x)$ are needed or transformation of variables is mathematically impossible and Monte Carlo simulation is also involved in these approximate methods. More recently, a general method for estimating the moments of a function with a number of random variables has been developed. This method presented by Rosenblueth[2)] is based on simple point evaluations of the function $y(x)$. The derivation of this method for a function of one variable $y(x)$ involves replacing a continuous density function of the independent variable $f(x)$ with a discrete mass function $p(x)$. The points x and their associated probabilities $p(x)$ are defined by matching the moments of the discrete mass function to the continuous density function $f(x)$.

We apply two and three point procedure to n-1 pairs of variables of soil parameters and analyze the probabilistic seismic response of the ground with n-1 surface layers. Figure 2 shows the probability mass functions of soil parameters, which are soil density and shearing modulus of elasticity at m-th layer, for two and three point estimates.

Equations for the relative displacement of the surface layer $U_1(\omega)$ in Monte Carlo simulation (MCS) and in two and three point estimates methods (PEM2 and PEM3) are as follows:

<MCS>

$$E[U_1(\omega)] = 1{,}000^{-1} \sum_{i=1}^{1{,}000} [\, U_1{}^{*}\{\omega, \rho(1,i), \rho(2,1), \ldots, \rho(n-1,i), G(1,i), G(2,i), \ldots, G(n-1,i)\}\,]$$

where $U_1{}^{*}$ means a relative displacement of the surface layer by using a pair of soil parameters.

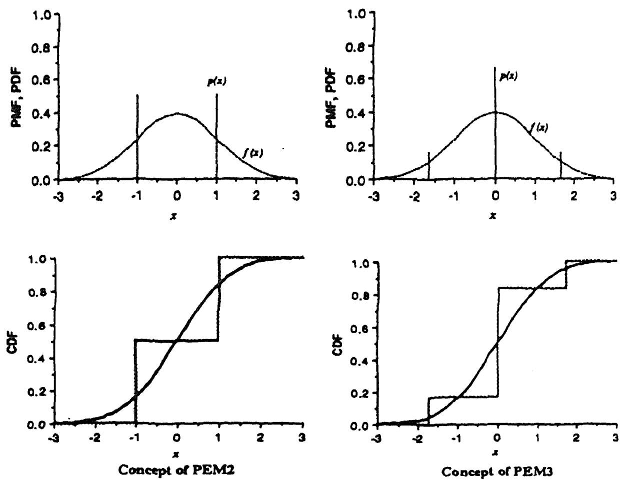


Fig.1 Probability density/mass and cumulative distribution functions.

<PEM2>

$$E[U_1(\omega)] = 0.25^{n-1} \sum_{i_1=1}^{2} \sum_{i_2=1}^{2} \ldots \sum_{i_{n-1}=1}^{2} \sum_{j_1=1}^{2} \sum_{j_2=1}^{2} \ldots \sum_{j_{n-1}=1}^{2} [\, U_1{}^{*}\{\omega, \rho(1,i_1), \rho(2,i_2), \ldots, \rho(n-1,j_{n-1}), \ldots, G(1,j_1), G(2,j_2), \ldots, G(n-1,j_{n-1})\}\,]$$

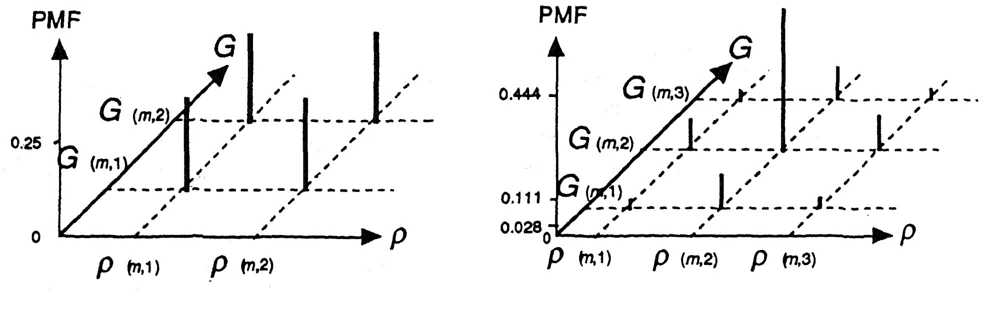
where, $\rho(m,1)=\rho_{Mm}-\sigma_{\rho m}$, $\rho(m,2)=\rho_{Mm}+\sigma_{\rho m}$, $G(m,1)=G_{Mm}-\sigma_{Gm}$, $G(m,2)=G_{Mm}+\sigma_{Gm}$. ρ_{Mm} and G_{Mm} are the means of soil density and shearing modulus of elasticity, $\sigma_{\rho m}$ and σ_{Gm} the standard deviations of those at the m -th layer, respectively.

<PEM3>

$$E[U_1(\omega)] = 0.028/4^{n-2} \sum_{i_1=1}^{2} \ldots \sum_{i_{n-1}=1}^{2} \sum_{j_1=1}^{2} \ldots \sum_{j_{n-1}=1}^{2} [\, U_1{}^{*}\{\omega, \rho(1,2i_1-1), \ldots, \rho(n-1,2i_{n-1}-1), G(1,2j_1-1), \ldots, G(n-1,2j_{n-1}-1))\,]$$

$$+\, 0.111/2^{n-2} \sum_{i_1=1}^{2} \ldots \sum_{i_{n-1}=1}^{2} [\, U_1{}^{*}\{\omega, \rho(1,2i_1-1), \ldots, \rho(n-1,2i_{n-1}-1), G(1,2), \ldots, G(n-1,2)\}\,]$$

$$+\, 0.111/2^{n-2} \sum_{j_1=1}^{2} \ldots \sum_{j_{n-1}=1}^{2} [\, U_1{}^{*}\{\omega, \rho(1,2), \ldots, \rho(n-1,2), G(1,2j_1-1), \ldots, G(n-1,2j_{n-1}-1)\}\,]$$



a) Weight used in PEM2.

b) Weight used in PEM3.

Fig.2 Probability mass functions of soil parameters.

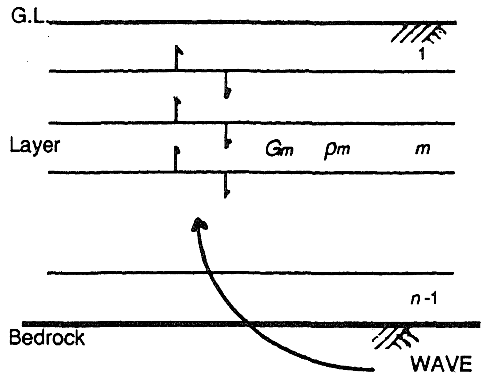


Fig.3 General view of seismic wave propagation.

Table 1 Model grounds.

Model 1

layer No.	Density(t/m^3)	Shearing modulus of elasticity(tf/m^2)	Thickness (m)
1	1.6	36,000	3.0
2	1.8	112,500	3.0
Bedrock	2.2	625,000	—

Model 2

layer No.	Density(t/m^3)	Shearing modulus of elasticity(tf/m^2)	Thickness (m)
1	1.9	34,550	3.0
2	1.9	67,000	3.0
3	1.9	59,570	3.0
4	1.9	75,700	3.0
Bedrock	2.2	625,000	—

$1\ t/m^3 = 1 \times 10^3\ kg/m^3$, $1\ tf/m^2 = 9.8\ kPa$

$$+0.444\,[\,U_1{}^*(\omega, \rho(1,2), ..., \rho(n\text{-}1,2), G(1,2), ..., G(n\text{-}1,2))\,]$$

where $\rho(m,1)=\rho_{Mm}-C\sigma_{\rho m}$, $\rho(m,2)=\rho_{Mm}$, $\rho(m,3)=\rho_{Mm}+C\sigma_{\rho m}$, $G(m,1)=G_{Mm}-C\sigma_{Gm}$, $G(m,2)=G_{Mm}$, $G(m,3)=G_{Mm}+C\sigma_{Gm}$, C value is 1.73 by Rosenblueth in case that the variable of soil parameter has a Normal destribution.

3 MODEL GROUND

General view of seismic wave propagation in the layered ground is shown in Fig.3. For simplicity, let us consider a case of forced vibration of the surface layer, caused by S waves which are incident vertically from bedrock. In this model, parameters of local soil condition in the ground directly affect not only on the wave propagation but also on ground response during earthquake motion. Simplified model of the ground used here is summarized in Table 1. These data are obtained from an actural ground, and we use these values as mean in the analyses. The coefficients of variation (C.O.V. = standard divi-ation / mean) of soil density and shearing modulus of elasticity are assumed to be 0.1 and 0.2[3].

4 COMPUTATION AND RESULTS

The1st natural frequency and response amplification at that frequency obtained here are listed in Table 2. Both relative errors of means of the natural frequency and response amplification of the linear ground are less than 3%, and those of the equivalent linear ground do not exceed 11%. Relative errors of means for all results are smaller than those for standard deviations(S.D.). Time executing computer program in the two point estimates method is remarkably shorter than that in Monte Carlo simulation. These facts suggest that the new method proposed here is very efficient and powerful in analyzing the seismic response of the layered ground with uncertainty in soil parameters.

It can also be concluded that the C.O.V. of the amplification and natural frequency is 0.19 great value for ordinary C.O.V. values on soil parameters in Monte Calro simulation. This fact leads us to an important conclution that the uncertainty in soil parameters is not negligible, especially for greater amplification in the low natural frequency.

It seems that relative errors become greater for increasing input acceleration level. This tendency is explained by the facts that softening of the soil modulus of elasticity makes the natural frequency decrease, and that even small difference between natural frequency obtained by point estimate method and that by Monte Carlo simulation influences directly the relative error.

5 CONCLUSION

This study deals with the seismic response of the layered ground, and points out the importance of considering the uncertainty in soil parameters of the ground. We presented a new probabilistic approach in evaluating the seismic ground response and discussed the effects on the response of the uncertainty in soil parameters. The

Table 2 Analytical results.

Model 1

	Linear				Equivalent linear			
	Amplification		Natural frequency(Hz)		Amplification		Natural frequency(Hz)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
MCS	8.70	1.14 [13]	9.29	0.96 [10]	16.40	3.20 [19]	5.37	0.74 [14]
PEM2	8.68	0.94 [11]	9.33	0.86 [9]	16.33	2.51 [15]	5.38	0.64 [12]
	(0.2)	(17.5)	(0.4)	(10.4)	(10.4)	(21.6)	(0.2)	(13.5)
PEM3	8.86	1.35 [15]	9.24	1.17 [13]	17.04	3.93 [23]	5.28	0.94 [18]
	(1.8)	(18.4)	(0.5)	(21.9)	(3.9)	(22.8)	(1.7)	(27.0)

Model 2

	Linear				Equivalent linear			
	Amplification		Natural frequency(Hz)		Amplification		Natural frequency(Hz)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
MCS	7.29	0.56 [8]	2.37	0.20 [8]	14.03	1.43 [10]	1.29	0.15 [12]
PEM2	7.25	0.47 [6]	2.38	0.18 [8]	14.01	1.29 [9]	1.30	0.13 [10]
	(0.5)	(16.1)	(0.4)	(10.0)	(0.1)	(9.8)	(0.8)	(13.3)
PEM3	7.44	0.72 [10]	2.35	0.26 [11]	14.45	1.83 [13]	1.27	0.18 [14]
	(2.1)	(28.6)	(0.8)	(30.0)	(3.0)	(28.0)	(1.6)	(20.0)

In the parenthesis ( ) : Relative error (%) [(PEM-MCS)/MCS × 100]
[ ] : C.O.V. (=S.D./Mean) of response of the ground (%)
S.D.: standard deviation

method which requires only a few evaluations of the function for each variable gives very good accuracy comparable to the results by the Monte Calro simulation.

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REFERENCES

1) Toki, K. 1981. Aseismic analysis of structure. Gihoudou-shuppan:82-105 (in Japanese).
2) Rosenbleuth, E. 1975. Point estimates for probability moments. Proceedings of the Natural Academy of Science 72-10:3812-3814.
3) Matsuo, M. 1984. Geotechnics - Ideology for reliability design and its practices -. Gihoudou-shuppan:62-64 (in Japanese).