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Seismic Analysis Using Synthetic Wave Based on the Dislocation Model to Simulate Ground Motions in the Hyogoken-Nanbu Earthquake 1995

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SEISMIC ANALYSIS USING SYNTHETIC WAVE BASED ON THE DISLOCATION MODEL TO SIMULATE GROUND MOTIONS IN THE HYOGOKEN-NANBU EARTHQUAKE 1995

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ABSTRACT

The Green function based on the kinematics dislocation model has been newly developed in association with the convolution scheme in time for source function and in space along rupture direction. Synthetic waves derived from this model are corresponding to the bedrock motion. The ground model is formed with 3D multi-thin layers and the soils are linear material. Inhomogeneous rupture mechanism in faults is considered in terms of multiple asperities gained from the inversion information.

In the shallow soils, non-linearity governs the dynamic behavior of the ground. Waves propagate with amplifications and absorption through the soft soil according to the frequency contents. Finite element analysis based on the plastic theory can include the dynamic properties of soils, the surface layer effects and the topographic conditions.

INTRODUCTION

Since the Hyogoken Nanbu earthquake happened in 1995, numerical and empirical estimation methods for synthetic ground motion near faults have been studied and developed. One of the authors has newly developed a numerical method using Green function for the force action based on the kinematics dislocation model. The ground motions can be synthesized from coupling the force and the ground model descritized with thin layers [1].

The synthetic ground motion was gained at the location of the Kobe University (KBU) to compare with the observed record at the basement of the university building on the soft rock. The KBU record is considered to represent a deep ground motion directly coming from the fault rupture through the rock foundation. The dislocation model produces a deep ground motion, so it would be comparative to this KBU record in order to judge whether the numerical model and method are adaptable to simulate ground motions.

Shallow soil effect is deeply affected the non-linearity of the soil and the topographic condition. Shallow ground motions can be simulated using some of the computer programs. We have used DYNAFLOW to simulate the ground motion at the Shinkobe substation near the Kobe University. Another earthquake record was gained at the ground level in this Shinkobe station. It gives another viewpoint to compare the observed record and the analytical result at the ground surface for realistic simulation based on the theoretical model only using the topological and the topographical conditions.

In this study, we are aimed to examine how much the synthetic ground motion can be practically simulated from the viewpoints of the deep ground motion and the shallow soil effect in comparison with the two observed records respectively. The use of small earthquake records at the target site has become effective to form the Green function that fulfills both the fault mechanism and the geological condition [2]. However, this empirical method needs earthquake records and is not applicable to the site without observation. Theoretical methods are necessary to approach synthesis of seismic motions for such site and enable parametric study.

DEEP GROUND MOTIONS

This simulation system takes the following numerical procedures.

1) The kinematics of the fault dislocation is considered by the equivalent force action on fault area. The vertical discretization is predetermined by the thin layer procedure and the horizontal discretization follows the rupture speed and time increment for analysis.
2) The rupture program is controlled by a radial proceeding model of the Kostrov type slip rate that takes into account the stress drops after the fault slip.
3) The solution method is based on the step-by-step integration

of the convolution integral of the moving Green function for the equivalent dislocation force action.

4) In adapting discrete wave number method the fundamental wavelength should therefore be predetermined according to the frequency contents considered.

Simulation results

Fig. 1 and 2 depict the fault area comprising three asperities that caused the Hyogoken Nanabu earthquake. Table 1 shows seismic parameters for the three fault asperities following the source information from inversion analysis. The site condition that includes the quantitative features of these asperities is given in Table 2. Fig. 3 show time histories of three waves gained for the same place at the Kobe University in the different ways.

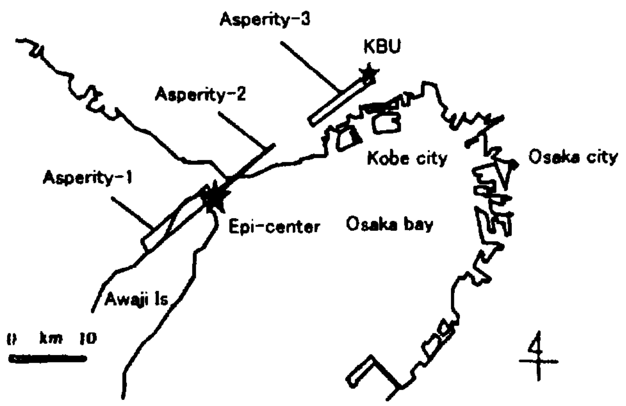

Fig. 1:Plan view of the fault segments

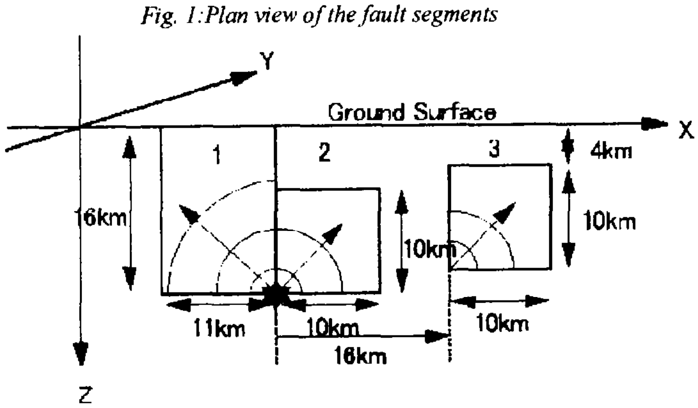

Fig. 2:Fault segments for the Hyogo Nanbu Eq.(1995)

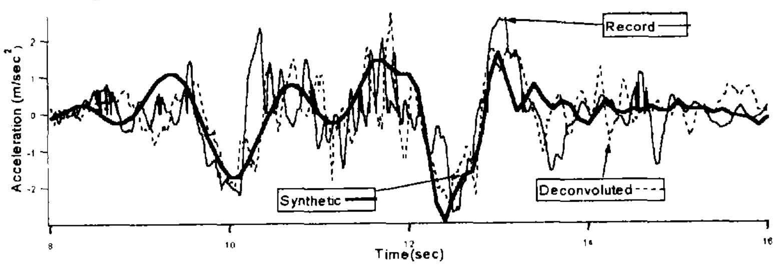

Fig. 3:Comparison of earthquake motions in three ways

The waves are only NS component of each wave since most structural analysis is carried out using one component and this study is targeting how much the ground conditions affect in seismic motions. Those three waves in fig.3 show good agreement in peaks and shapes. "Record" in the figure is the observation record at the Kobe University. "Synthetic" is the result of this study using the dislocation model at the same point. "Decovoluted" is obtained from the devolution of the record at Shinkobe substation next to the Kobe University using another program FDEL based on the frequency-dependant equivalent strain for equi-linearized technique [4].

Table 1:Seismic parameters

Segment No	Time	MO	Strike, Dip, Rake	Area	Slip
	(sec)	($\times 10^{19}$Nm)	(degree)	(km^2)	(m)
1	0~7.2	1	(233,85,175)	11*16	1.6
2	0~5.0	0.34	(233,110,30)	10*10	0.9
3	6.2~11.2	0.18	(233,100,60)	10*10	0.5
Total	0~11.2	1.52			
	Rise time =0.6(sec) Rupture velocity (Vr)=2.8(km/sec)				

Although synthetic wave in Fig. 3, shows long and gradual acceleration curve, the trend and the pick are similar to the KBU.

In Fig. 4, the peak frequencies of the three waves agree well. However, some differences are noticed in the low frequency range around 0.4 Hz and the high frequency range above 3 Hz. Synthetic wave is over estimated in the low frequency range and underestimated in the high frequency range. The reasons for such differences are:

1) The accuracy of the computation depends on the minimum size of the discretization of time and space while numerical residual errors are avoided.
2) The fracture mechanism and the ground model are simplified without including irregularity in the site condition.

Due to these reasons, synthetic waves may tend to be amplified in the low frequency range and diminished in the high frequency range in this study the deconvolution wave is much affected by the shallow soils.

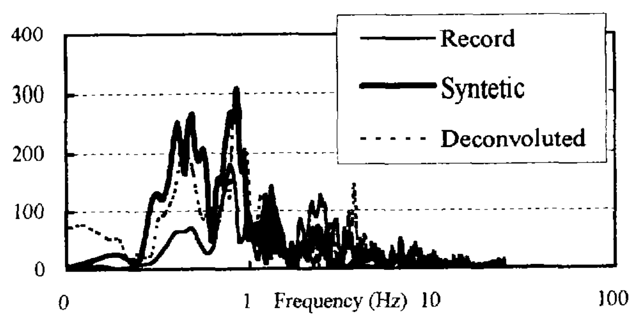

Fig 4:Fourie spectrum for each wave

In the next section, we discuss how the non-linearity affects amplification in the ground motion using a 1D model.

Table 2:Soil parameters

Layer	*Thickness*	*S wave velocity*	*Poisson's ratio*	*Density*
	(km)	(km/sec)	μ	($\times10^9$t/km^3)
1	0.7	1.4	0.272	1.8
2	1.2	2.3	0.253	2.0
3	1.5	3.0	0.251	2.4
Bottom layer	∞	3.5	0.242	2.8

SITE EFFECTS IN SHALLOW SOILS

The previous stage of this study mentioned source and pass problems in the simulation of ground motions. The geological conditions are simply interpreted as linear materials.
In this stage, non-linear analysis was conducted taking account of strain dependant characteristic in the soil shear modulus and damping. The computer program, DYNAFLOW, has versatile capabilities and some features in describing the constitutional model by the multi-yield plastic theory [5].

The multi-thin layer model is one dimensional with the same horizontal movements at the both sides of the model, although Fig. 5 shows a rectangular model with 100m horizontal widths and 65m depths. The soils are granite at the bottom of layers and weathered granite, equivalent to granular soils, at the surface. Especially top 2 or 3m soil deeply affects the amplification of the ground motions because of its non-linearity. The shallow soil has higher non-linearity than that of the deep soil at the site in terms of the strain-dependant shear modulus and damping.

Dynaflow takes material property in different ways. One of the options, taken in this study, is the way that initial shear modulus Go and maximum shear stress τ max and maximum shear strain γ max describe the constitutive low of the material using a parabolic relationship as shown in Fig. 6. The curve can be described using these soil parameters gained from the results of three axial tests without conducting special dynamic lab tests.

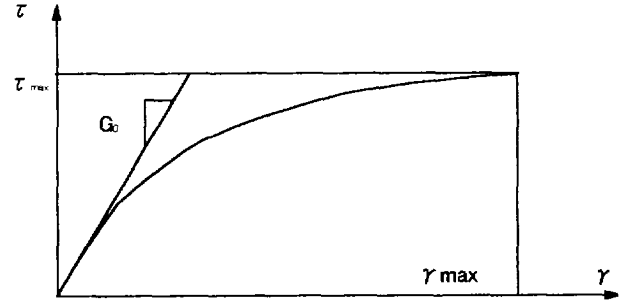

Fig. 6:Constitutive model

The main property of each layer is shown in Table 2. Subdivided layers with less than 2m composed the ground model in fig.5. The ground motion was applied at the rock foundation GL−65m. Sands and soft rocks cover the ground with the thickness of 24m and 38m respectively.

Table 3:Surface soil parameters

Layer No	Thickness (m)	Density (g/cm^3)	S wave velocity (m/s)	Soil
1	3	1.6	200	Sand
2	7	2	300	Sand
3	4	2	450	Sand
4	13	2.1	450	Sand
5	6	2.2	690	Rock
6	12	2.1	450	Rock
7	20	2.3	640	Rock
8	Foundation	2.3	640	Rock

The observed record at the surface of the ground Shinkobe substation has low frequency content (0.46Hz). On the other hand, the computation result does not have corresponding frequency content (2.2Hz~3.3Hz) was amplified. One of the reasons for these differences is, though that the high frequency content is affected the natural frequency of the ground model (1.75Hz) from the following equation.

$$T = 4\frac{\Sigma H}{\Sigma Vs} \qquad (1)$$

Where T: natural period (sec)
H: thickness of each layer (m)
Vs: S wave velocity (m/sec)

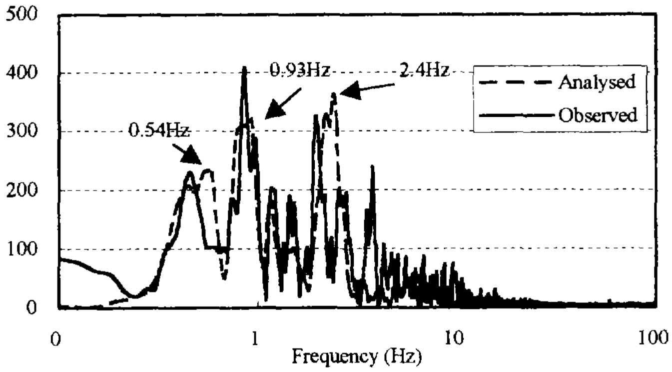

*Fig. 7:*Fourie spectrum for the ground surface motions

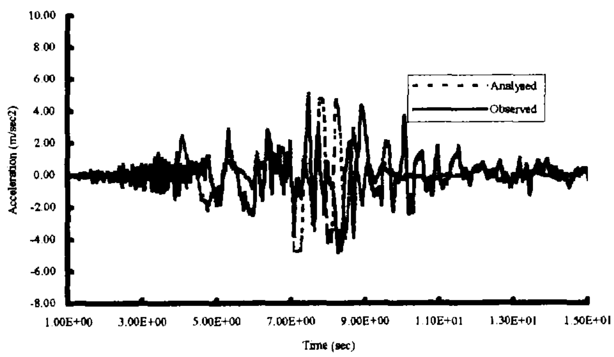

*Fig. 8:*Time histories of the ground surface motions

The analyzed ground surface motion shows earlier amplification around 6 sec than that of the observed and less degradation in Fig.6. The maximum acceleration and the amplification from the deep ground to the top fairly agree with each other as shown in Table 4. The peak accelerations of both waves are approximately same but the analyzed peak acceleration is slightly bigger than the observed one. The amplification of the maximum acceleration is about 2 times of the ground motions and it occurs mostly within the top sand layers of 10m depths.

Table — 4:Comparison of the ground surface motions

Maximum acceleration			
	Deep ground motion (gal)	Surface ground motion (gal)	Amplification (times)
Analyzed	267	590	2.2
Observed	270	510	1.9

CONCLUSION

Two-step analyses were conducted for the simulation from the fault to the ground surface. The first step was carried out using the dislocation model from the fault to the site in the deep ground. The second step was carried out using another seismic response program.

In the deep ground, the simulation by the means of the dislocation model gives synthetic motions in agreement with the observed record at the Kobe University in terms of the maximum acceleration and the shape of the waves. Viewing the fourie spectrum, the synthetic wave contains low frequency components (<1Hz) more than that of the record while high frequency components (>1Hz) were less computed.

In the second step, the material non-linearity of the soils was taken into account in the study of the site effects for the shallow ground. The amplification from the deep ground to the surface was about two times of the input motion. The peak of the ground motions was in good agreement. The dominant frequency of the deep ground motions shows good agreement, but the frequency contents changed in the analytical process in consideration of the shallow soil effects. The high frequency contents (2.2Hz~3.3Hz) were overestimated in the one dimension model. The rigid boundary condition and the lack of spatial dissipation may affect the results. Further study will be reguired.

REFERENCES

[1] Takemiya, H. and Goda, K (1999),"Simulation of near source ground motions due to discretized dislocation in layered soil."

[2] Irikura, K. (1983), "Semi-empirical estimation of strong ground"

[3] Kamae, K. and Irikura, K. (1997), "A fault model of the 1995 Hyogo-ken Nanbu Earthquake and simulation of strong ground motion in near-source are", J. Struc. Constr. Eng. Architechtureal Institute of Japan, 500, 29-36

[4] Sugito, M. (1995), "Frequency-Dependant Equivalent Strain for Equi-Linearized Technique", Proc. of Is-Tokyo'95, The First International Conference on Earthquake Geotechnical Engineering, Tokyo, pp. 655-660

[5] Prevost, J. H. (1988),"DYNA1D: a computer program for nonlinear seismic site response analysis", Report No.NCEER-88-xxxx, Dept. of Civil Eng. and Oper. Re., Princeton University.