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From Case History to Practice | In honour of Prof. Kenji Ishihara

ESTIMATION OF DYNAMIC SOIL PROPERTIES USING DOWNHOLE ACCELERATION RECORDS

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EXTENTED ABSTRACT

In geotechnical engineering, dynamic characteristics of soils are usually estimated from field and laboratory tests. As an alternative and more practical method, dynamic soil properties can be predicted using strong motion earthquake records measured in downhole array of accelerometers. For this purpose, various system identification techniques were used by many researchers. Chang et al.(1982), Cakmak and Sherif (1984) demonstrated that dynamic site response can be described with low order ARMA (Auto-Regressive Moving Average) models and proposed a relationship between the model and physical parameters of array sites. Elgamal et al. (1996) performed correlation and spectral analyses to evaluate shear wave propagation characteristics, variation of shear wave velocity with depth and site resonant frequencies. Gunturi et al. (1998) predicted low strain response of soils by calculating average shear wave velocities of array sites and obtaining average shear modulus and damping ratio using a linear soil model. Baise (2000) investigated dynamic site response in several array sites using transfer function identification, correlation analyses, and full waveform modelling. Oskay (2002) proposed an iterative algorithm to identify maximum and elasto-plastic shear moduli using a nonlinear constitutive model in 2-D and 3-D soil systems. In this study, the system identification techniques were examined for estimation of dynamic soil properties in LA Cienega array site (Center for Engineering Strong Motion Data) from acceleration records.

LA Cienega array site consists of 4 borehole accelerometers located at the surface, at depths of 18.3m, 100.6m and 252m (Figure 1). The soil stratum along the array consists of mostly silty sand, thin silt and clay layers. The WHollywood Earthquake (2001) with 0.49g pga and the Inglewood Earthquake (2009) with 0.11g pga were selected as strong motion records to be employed in this study.

Two system identification approaches were used in order to estimate the dynamic soil properties. In the first approach dynamic soil properties were estimated without using any soil constitutive model, while in the second approach, a linear constitutive model was used.

In the first approach, maximum shear wave velocity (V_{Smax}) and the maximum shear modulus (G_{max}) of each soil layer were obtained using acceleration records at each depth via cross-correlation technique (Bendat and Piersol, 1980). Approximate shear wave velocities for each layer starting from the surface were estimated as 183m/s, 433m/s ,630m/s which are in good agreement with the field test results being 250m/s, 400m/s, 650m/s respectively. The goodness of fit of the estimated results is shown in Figure 1. Statistical auto regression analysis for time series was used in order to obtain the natural frequencies and the damping ratios of the soil layers. In this analysis a linear ARMA model was used and the model parameters were calculated using least squares approach for Inglewood and

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WHollywood earthquakes. The estimated dynamic soil properties obtained from ARMA model for WHollywood earthquake is presented in the Table 1. Prediction capabilities of the selected models for channel 1 and channel 4 are depicted in the Figure 2 by comparing the real acceleration records and predictions obtained from the ARMA estimated model. The ARMA model estimated using Inglewood earthquake acceleration record was used in order to obtain WHollywood earthquake acceleration predictions.

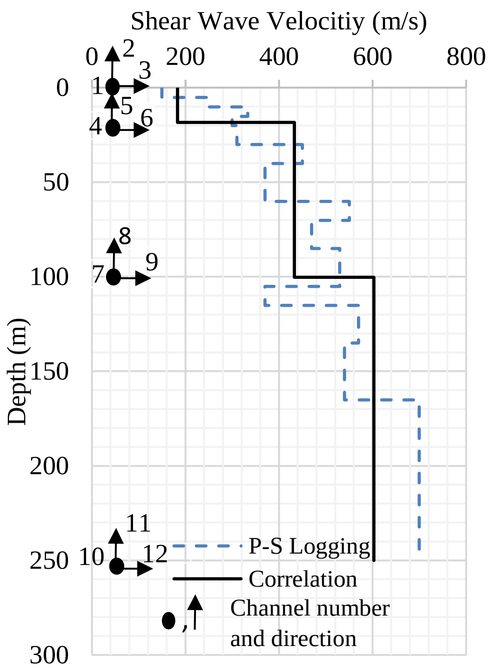

Figure 1. Comparison of shear wave velocities obtained from correlation analyses and P-S logging tests.

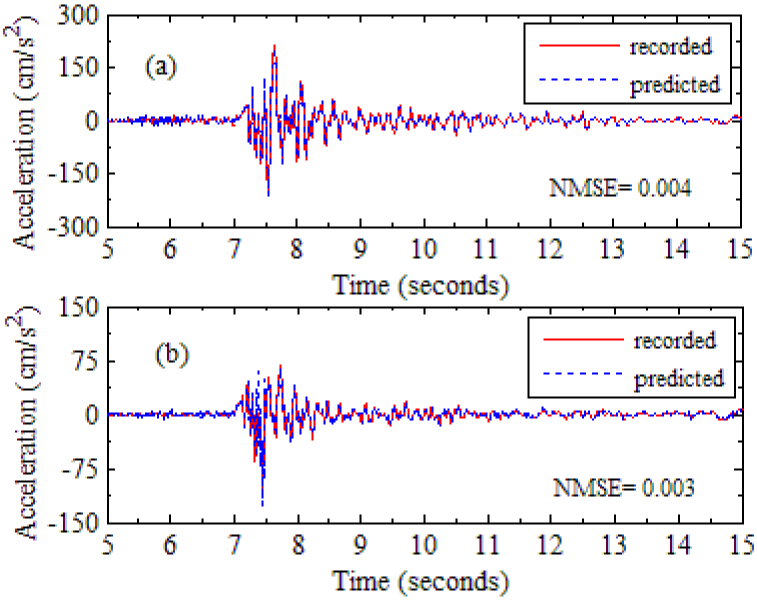

Figure 2. Comparison of predicted and recorded acceleration records for channel 1 (a) and channel 4 (b). (NMSE - Normalized Mean Squared Errors)

In the second approach, strain time histories were computed in the middle of each soil layer using displacement time records and shear beam idealization assumption. Stress time histories were obtained from strain estimates using a linear stress-strain relationship. The error between the predicted and optimized shear stresses were minimized using least squares approximation which depends on the shear modulus and viscous damping variables in the linear constitutive model. The comparison of the results demonstrated that linear constitutive model was adequate to predict the dynamic soil properties. For each layer, starting from the surface, the shear moduli were calculated as 162 GPa, 381 GPa and 853 GPa, which are in good agreement with the shear moduli estimated from the field tests. In Figure 3, the comparison of the shear stresses calculated from real acceleration records and predicted using dynamic soil properties obtained is shown for WHollywood earthquake.

Table 1. Estimated dynamic soil properties obtained from ARMA model (WHollywood earthquake)

		Modes		
Intervals		1st Mode	2nd Mode	3rd Mode
ch01-ch04	Natural Freq. (Hz)	4.95	13.54	28.18
	Damping Ratio, %	42.6	19.2	13.9
ch04-ch07	Natural Freq. (Hz)	5.84*	7.44	14.08
	Damping Ratio, %	100	46.1	46.7
ch07-ch10	Natural Freq. (Hz)	6.13	9.08	16.24
	Damping Ratio, %	43.1	53.7	10.8

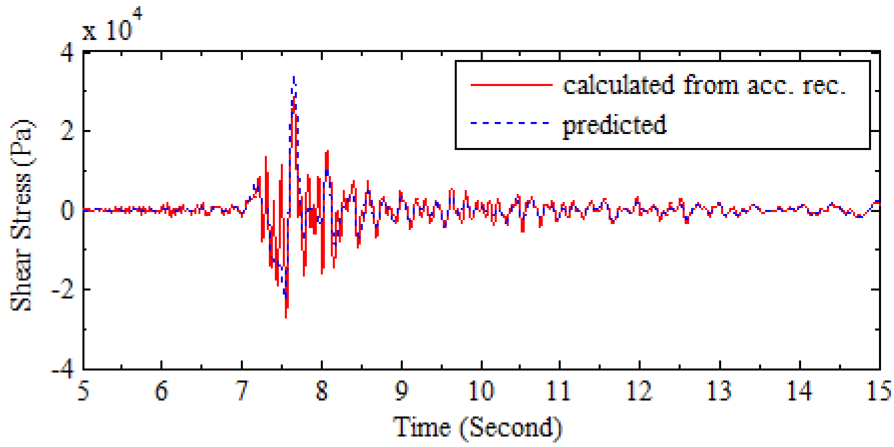

Figure 3. Comparison the shear stresses calculated from real acceleration records and estimated using dynamic soil properties obtained using linear constitutive model for WHollywood earthquake (in the middle of the soil layer between channel 1 and channel 4).

This study aims to predict dynamic soil behaviour of a site based on the strong motion data recorded in downhole arrays using common system identification techniques explored in geotechnical earthquake engineering. Two system identification approaches were examined in order to estimate the dynamic soil properties. In the first approach dynamic soil properties were estimated without using any soil constitutive model, while in the second approach, a linear constitutive model was used. Examinations show that dynamic soil properties can be estimated with a good approximation using system identification techniques and acceleration records. In the second approach, a linear model was used, the model captured average values for all length of the data, according to analyses results, and this model can be practically used to estimate soil properties. If such arrays are more implemented in seismically active areas, estimation of dynamic behaviour of these areas can be more improved.

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