# Identification Method of Dynamic Properties of Ground based on the Seismic Observation Record

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**ABSTRACT :**

We expressed the average shear strain and stress of the target soil layer using observed absolute accelerations at upper and lower boundary surface in the target soil layer, and the Zeghal method was applied. We examined the applicability of the Modified Zeghal's method using analytical results from multiple reflection theory. In the low shear-strain domain, shear stiffness and damping ratios were widely distributed around the actual position. On the other hand, in the high shear-strain domain, the values were converged to target values. Then, We applied the method to observed seismic records. The identified values of shear stiffness showed good agreement with the result of dynamic tri-axial tests. The variation of the identified damping ratio was large, and the difference from the result of dynamic tri-axial tests was also large. But, the calculated resonant curve showed good agreement with the observed curves, when response analysis was performed using the identified damping ratio. Consequently, the identified damping ratio represents the behavior of the entire layered soil system. The larger identified damping ratio compared to the result of dynamic tri-axial tests suggests radiation and/or scattering damping or the existence of a sand-particle friction effect.

**KEYWORDS:** Identification, Dynamic soil parameters, Modified Zeghal's method

## 1. INTRODUCTION

Identification of soil layer parameters, such as shear stiffness and damping ratio, based on seismic observation records will be very useful for earthquake resistant design. Zeghal has proposed a technique to identify shear moduli and damping ratios of soil layers based on observed records. These soil layer parameters are evaluated from a hysteresis loop in shear stress versus strain, which is treated as an equivalent linear ellipsoid.

In this paper, we propose the identification method which improved the Zeghal method, and we examine the applicability of the proposal method using analytical results from multiple reflection theory, where signal are used without noise. We then apply the method to actual seismic records observed by the vertical array installed in the Niijima sand ground during the Izu Islands earthquake swarm and on Funabashi campus in College of science and technology, Nihon University, and we consider the relation of sand shear strain and shear moduli and damping ratios of the ground.

## 2. MODIFIED ZEGHAL'S METHOD

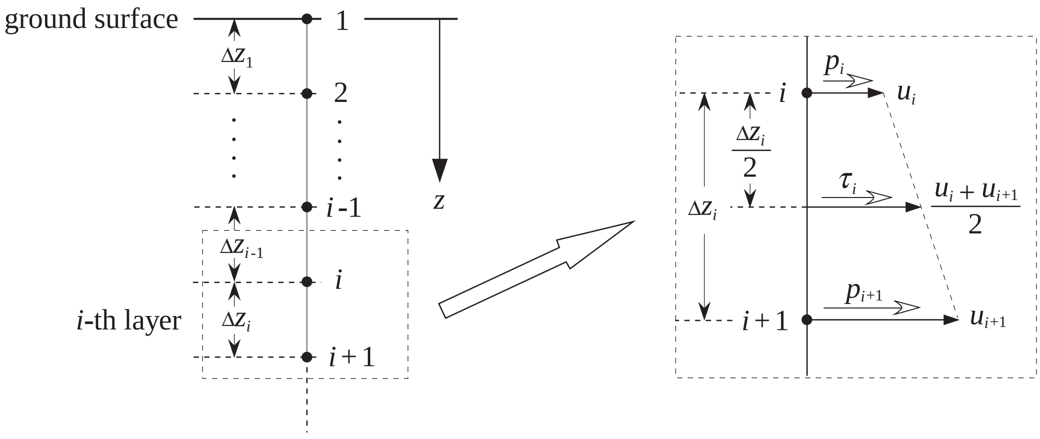



Figure 1 Structure of horizontal stratification

Shear strain $\gamma_i$ and shear stress $\tau_i$ in the *i*-th layer of a horizontal stratification shown in Fig. 1 are expressed by the following formula

$$\gamma_i = \frac{1}{\Delta z_i}\left(u_{i+1} - u_i\right) \tag{2.1}$$

$$\tau_i = p_i + \frac{1}{2}\rho_i \frac{\Delta z_i}{2}\left(\frac{\ddot{u}_i + \ddot{u}_{i+1}}{2} + \ddot{u}_i\right) = p_i + \frac{1}{8}\rho_i \Delta z_i\left(3\ddot{u}_i + \ddot{u}_{i+1}\right) \tag{2.2}$$

where $u_i$ and $p_i$ are observed absolute displacement and the shear force at the upper boundary surface of the *i*-th layer respectively, $\rho_i$ and $\Delta z_i$ are unit volume mass and layer thickness of the *i*-th layer respectively. $\gamma_i$ shown by Eqn.2.1 and $\tau_i$ shown by Eqn. 2.2 are the average shear strain and the average shear stress of the *i*-th layer respectively. Therefore, $\gamma_i$ and $\tau_i$ are equivalent to the shear strain and shear stress at the middle point of the layer respectively, and the shear force $p_i$ is written as

$$\left.\begin{aligned} & p_1 = 0 \\ & p_i = p_{i-1} + \frac{1}{2}\rho_{i-1}\,\Delta z_{i-1}\left(\ddot{u}_{i-1} + \ddot{u}_i\right) \qquad (i = 2, 3, \cdots) \end{aligned}\right\} \tag{2.3}$$

The time histories of the absolute displacement are transformed by integrating the observed absolute acceleration twice using Fourier integration.

## 3. INVERTIGATION METHOD AND RESULTS

### *3.1. Application to One-Dimensional Multiple Reflection Theory Model*

The simulated time histories of the shear stress and strain were calculated based on multi-reflection theory for a numerical layer model. Those time histories are shown in Fig. 2. It is not possible to observe the stress and strain waves, but they can be estimate using other absolute acceleration of two points. Therefore, we identified the stress and strain waves based on the formula above. Fig.2 shows the identified time histories of the shear strain and stress compared with the simulated wave. The identified responses are in excellent agreement with the simulated ones.

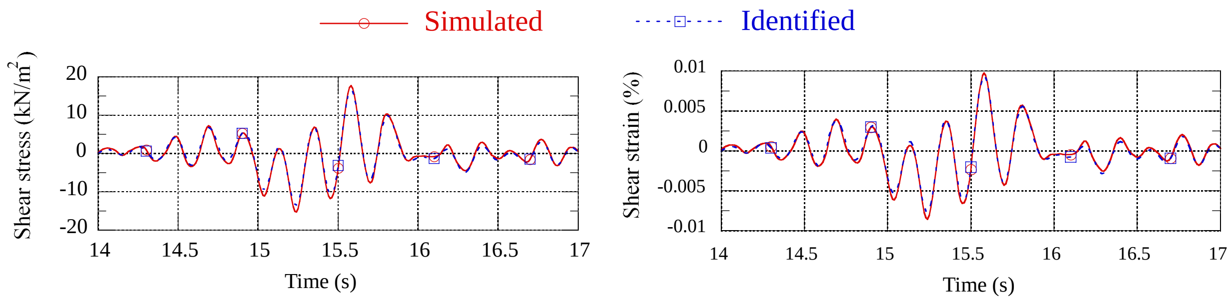



Figure 2 Time histories of shear stress and strain

The shear modulus *G*s is identified from the inclination and the damping ratio *h*s is identified from the ellipsoid area of hysteresis loops of shear stress versus strain using both simulated and identified time histories. The identified parameters, *G*s and *h*s, from both the simulated and identified responses are compared in Fig. 3. In the low shear strain domain, shear moduli and damping ratios are extended around the target values. On the other hand, in the high shear strain domain, the values converged to the target values.

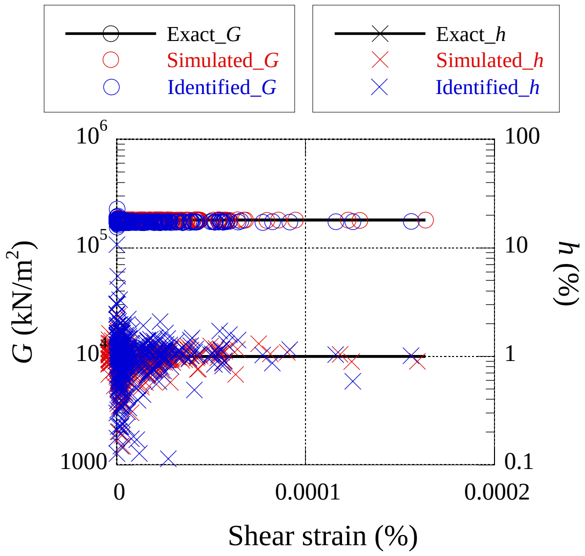


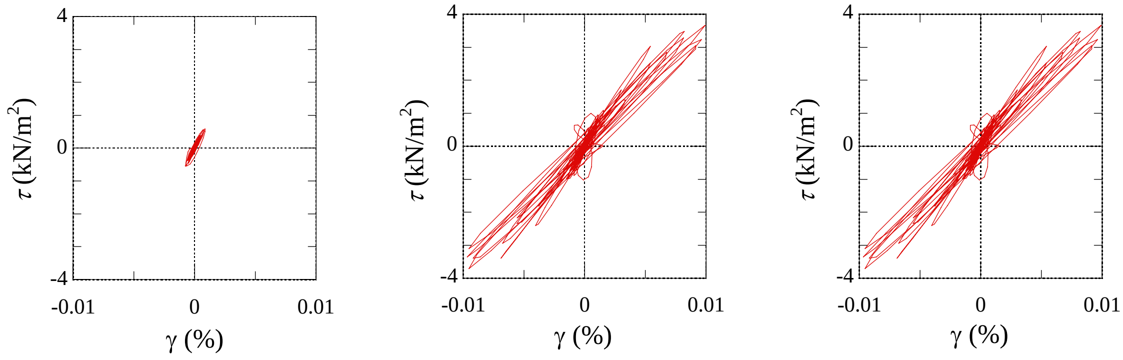

Figure 3 Shear moduli and damping ratio

### *3.2. Application to Actual Observed Records*

*3.2.1.Application to Actual Observed Records in Niijima*

Observation were carried out using a vertical array install in the sandy layer during the Izu Islands earthquake swarm. The number of observed points was two, that is at the ground surface and at a depth of 4.92 m. The observed records were classified into three groups according to the maximum acceleration of the surface : over

60 gal, 60 to 20 gal and under 20 gal. The hysteresis loops obtained are shown in Fig.4.




(a) Max. Acc. 20 gal (b) Max. Acc. 110 gal (c) Max. Acc. 200 gal

Figure 4 Shear stress–strain histories (hysteresis loops)

The sand rigidity *G* and the critical damping ratio *h* obtained from the loops for the identified results are shown in Figs. 5 and 6, compared with geotechnical three-axes dynamic test results using the extracted samples. The horizontal axes of both figures show shear strain. The sand rigidity decreased as the shear strain grew, and there is good agreement with the geotechnical test result. The damping ratio are widely distributed, like the identification example in the numerical model described above, and agreement with the geotechinical test results could not be verified.

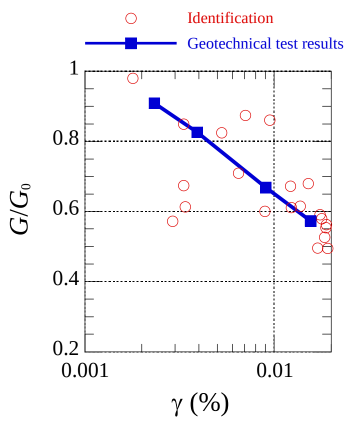



Figure 5 Shear moduli

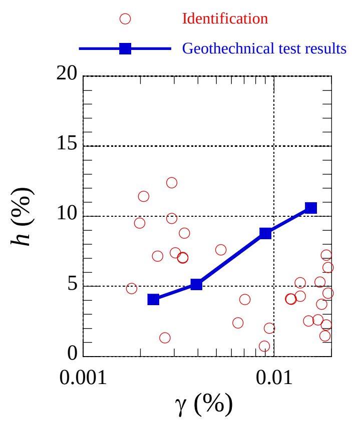



Figure 6 Damping ratio

When response analysis was performed using the identified value *h* in the low strain domain, the calculated resonant curve showed good agreement with the observed curves, as shown in Fig. 7. On the other hand, the simulated peak near *h* = 3 % (standard values of *h* are approximately 2 % to 3 % at low strain domain) has a sharp peak.

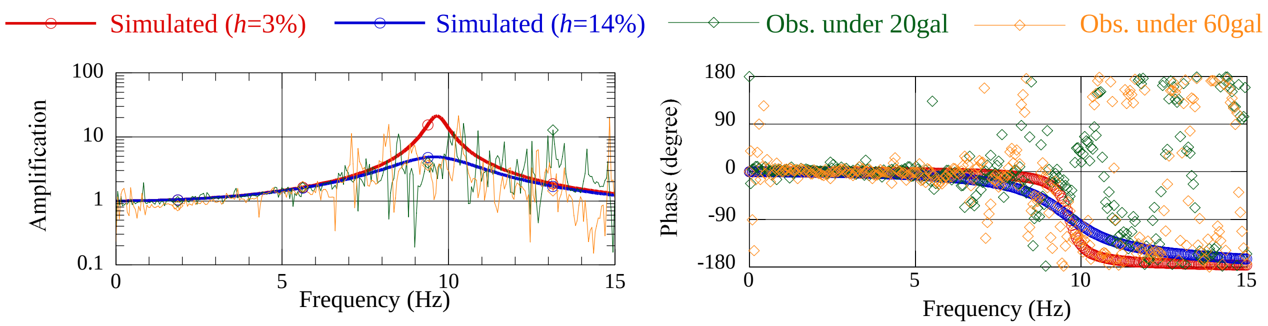



Figure 7 Amplification function (GL-0 m / GL-4.92 m)

*3.2.2. Application to Actual Observed Records on Funabashi Campus in Nihon University*

We have observed the ground motions in cooperation with the departments concerned in Funabashi campus of Nihon University since 1992 to grasp the characteristic of seismic ground motions. Fig. 8 show the geophysical logging result of the observation point and the positions of seismometers arranged on the ground surface and 5 points in the underground.

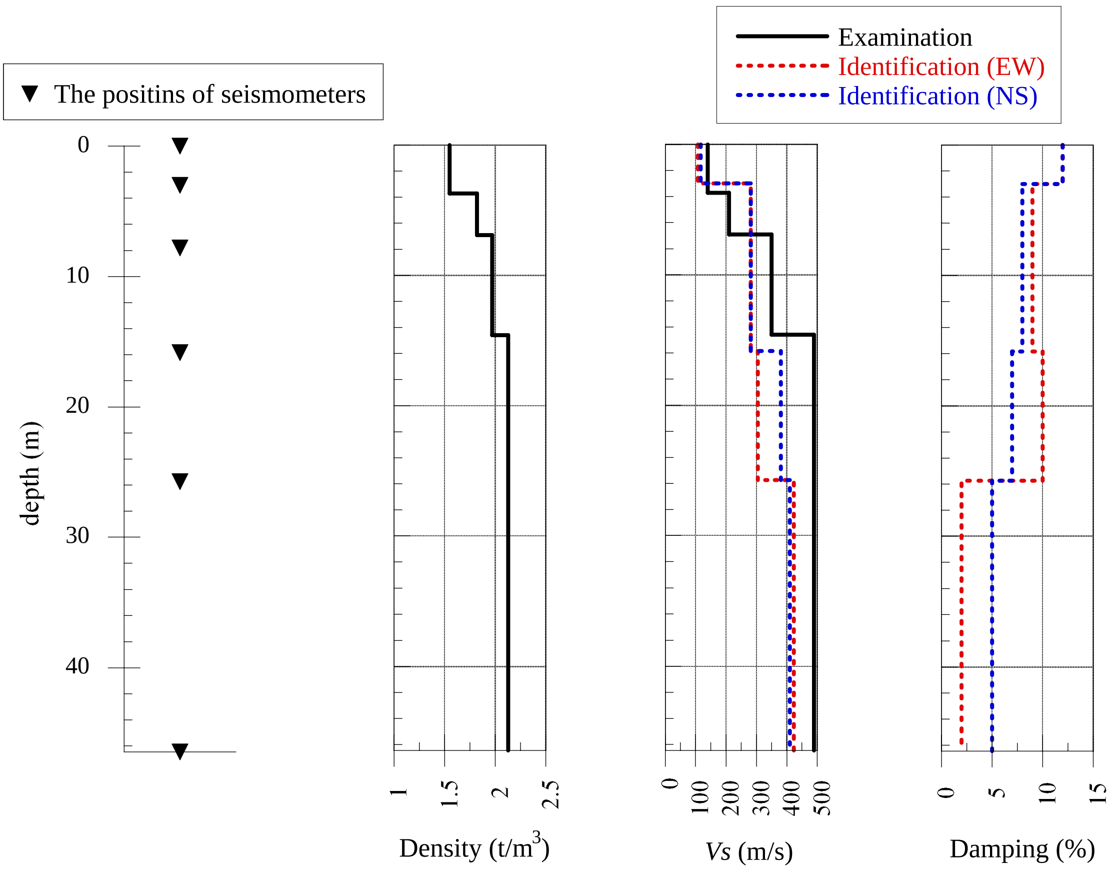
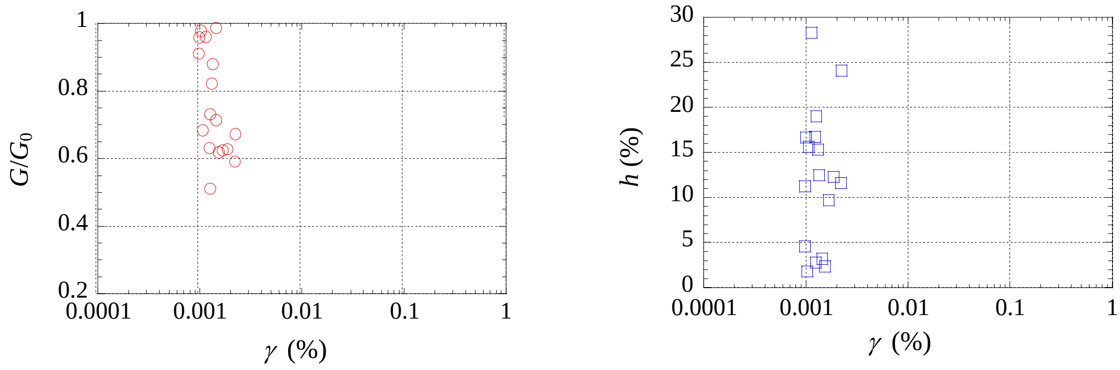


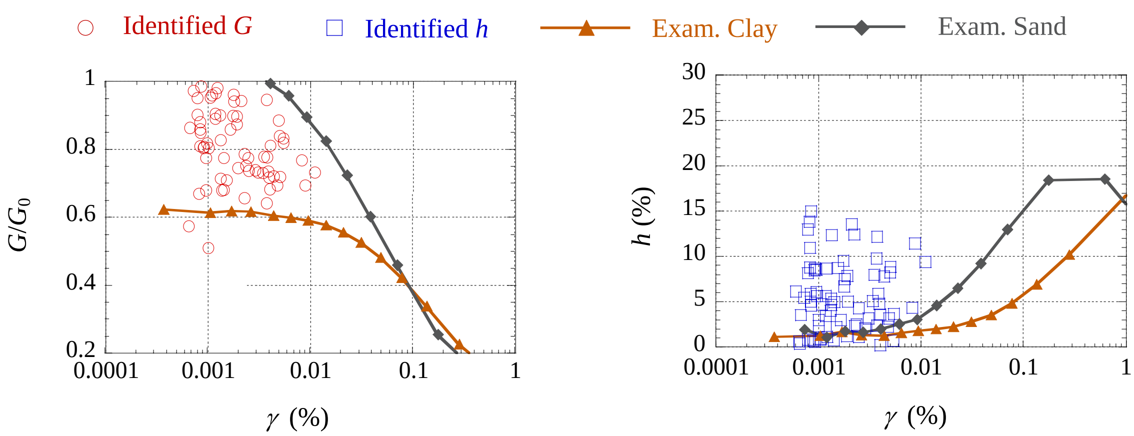

Figure 8 Geophysical logging result of the observation point and the positions of seismometers

The soil rigidity *G* and the damping ratio *h* obtained from the loops for the identified results using the seismic wave in which the ground level acceleration is around 100 gal are shown in Figs. 9 ~ 12.



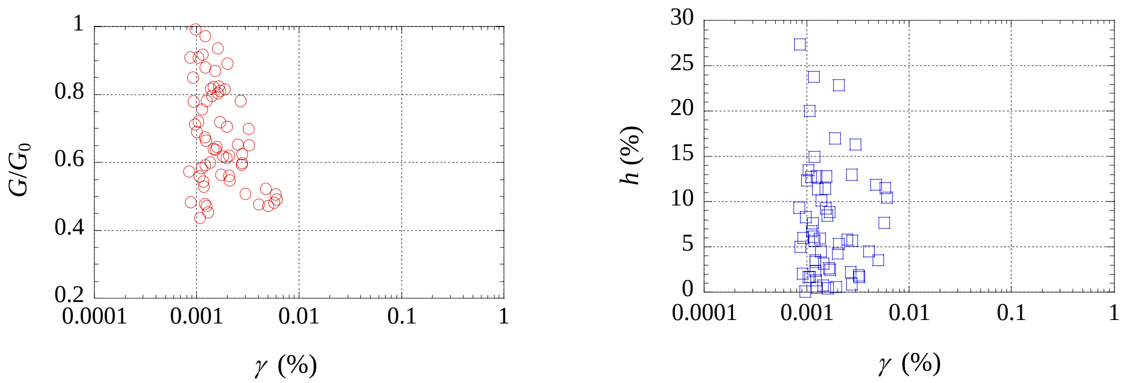

(a) Shear modulus (b) Damping ratio

Figure 9 Identified results using both observed acceleration at ground surface and at a depth of 3 m



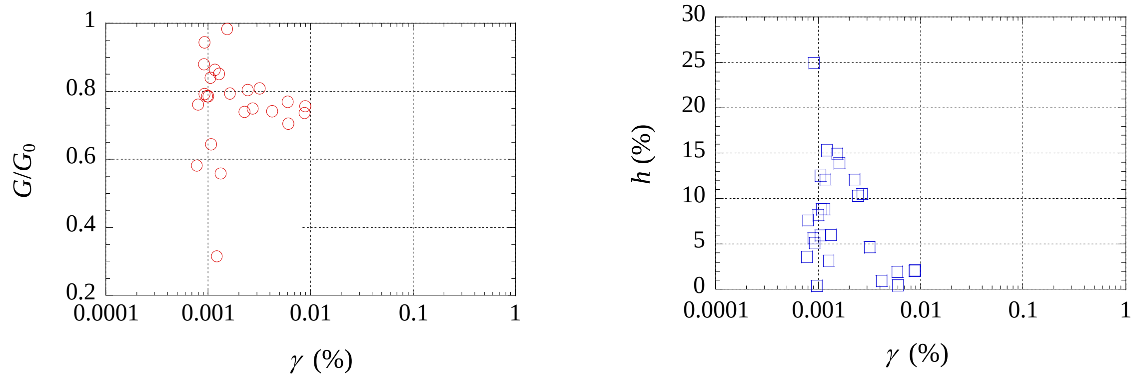

(a) Shear modulus (b) Damping ratio

Figure 10 Identified results using both observed acceleration at a depth of 3 m and at a depth of 15 m




(a) Shear modulus (b) Damping ratio

Figure 11 Identified results using both observed acceleration at a depth of 15 m and at a depth of 25 m




(a) Shear modulus (b) Damping ratio

Figure 12 Identified results using both observed acceleration at a depth of 25 m and at a depth of 45 m

The geotechnical three-axes dynamic test results of clay and sand are also shown in Fig. 10. The identified value *G*s are distributed between geotechnical three-axes dynamic test results of clay and sand. The identified damping ratio *h*s are widely distributed, like the identification cases of the Niijima described above, and agreement with the geotechinical test results could not be verified.

The numerical layer model using the identification values near the largest shear strain is shown in Fig. 8 by dashed line. When response analysis was performed using this layer model, the simulated resonant curve showed good agreement with the observed curves near the first resonance, as shown in Fig 13.

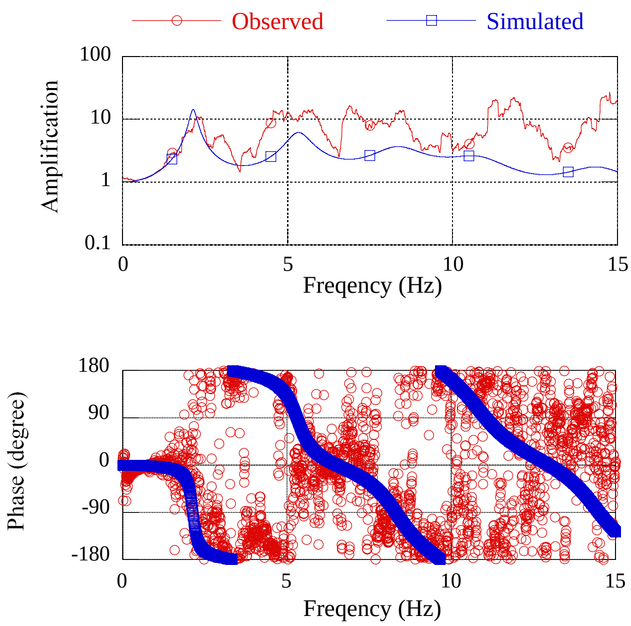



Figure 13 Amplification function (GL-0 m / GL-45 m)

## 4. CONCLUSION

We applied the modified Zeghal method to response analysis and verified its applicability. Using observed seismic records, the identified values of shear moduli showed good agreement with geotechnical test results. The variation of the identified damping ratio was large, and the difference from the soil-test value was also large. When response analysis was performed using the identified value of damping ratio, the calculated resonant curve showed good agreement with the observed one. Consequently, the identified damping ratio represents the behavior of the entire layer soil system. The larger identified damping ratio compared to the soil-test results suggests radiation and/or scattering damping or the existence of a sand-particle friction effect.

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