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INVESTIGATION ON SOIL NONLINEARITY BASED ON RECORDED SEISMIC DATA

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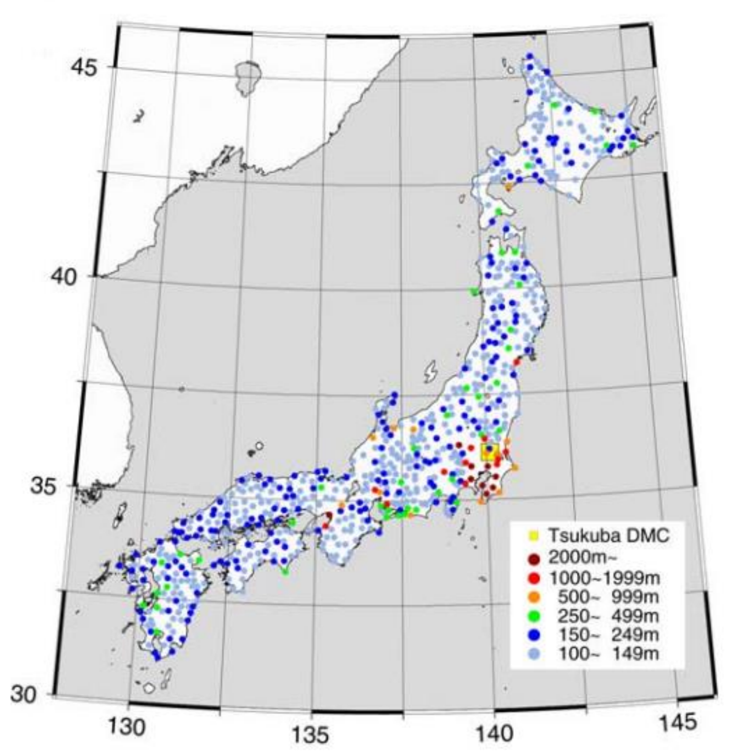
Introduction

Nonlinearity is one of the critical characteristics for geotechnical materials, and is usually interpreted by the stiffness degradation at different deformation levels. Traditionally, such investigations are carried out by laboratory tests or in-situ tests. However, laboratory tests poses some uncertainties in the prediction of soil nonlinear properties, and conducting in-situ tests are complex and expensive. Hence, in this project, the investigation of nonlinear behaviour of gravelly soils in Japan, in terms of shear modulus degradation, are based on the Japanese KiK-net down-hole array seismic in-situ observation.

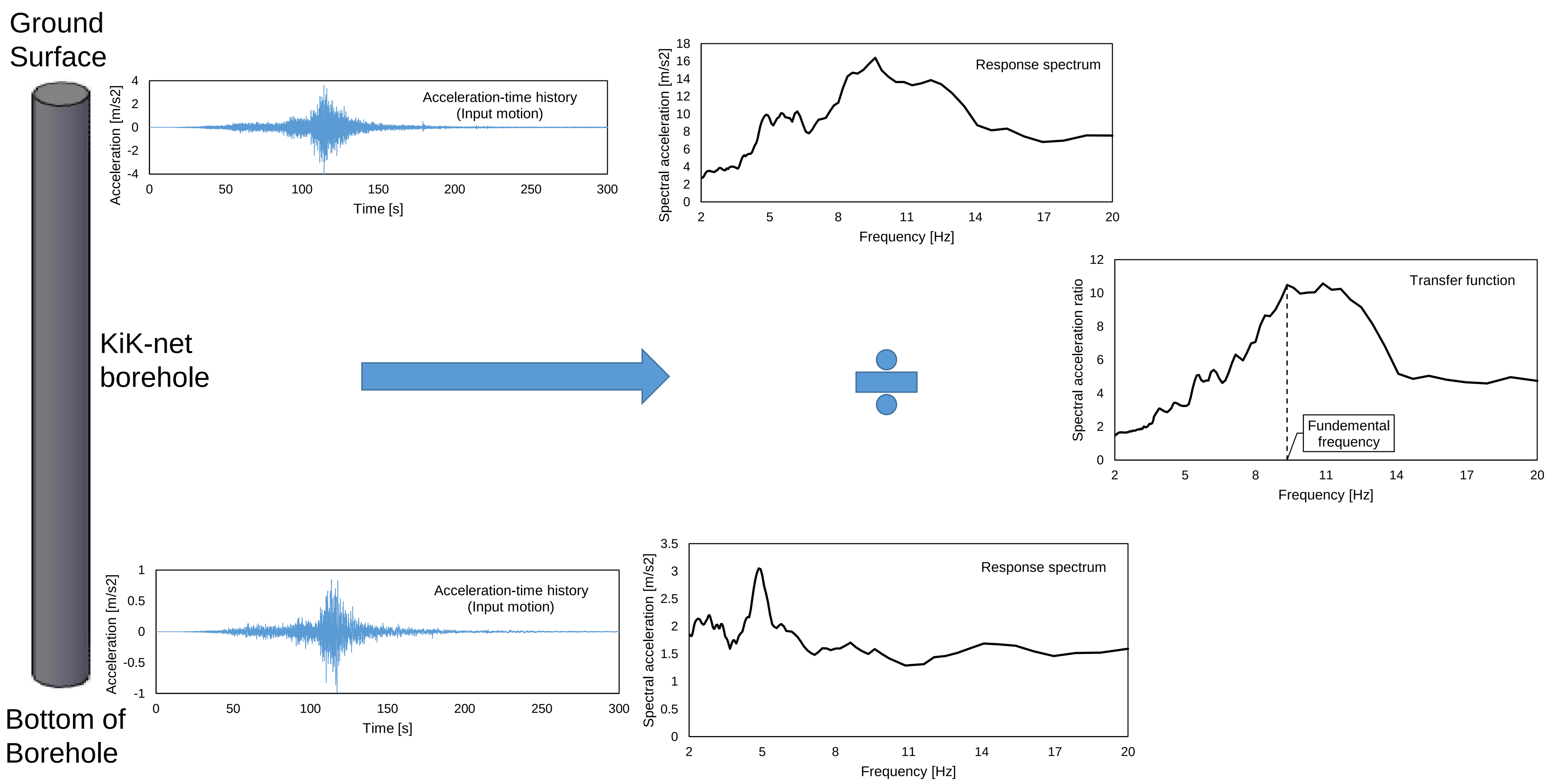
KiK-net down-hole array seismic observation system



Distribution of KiK-net stations

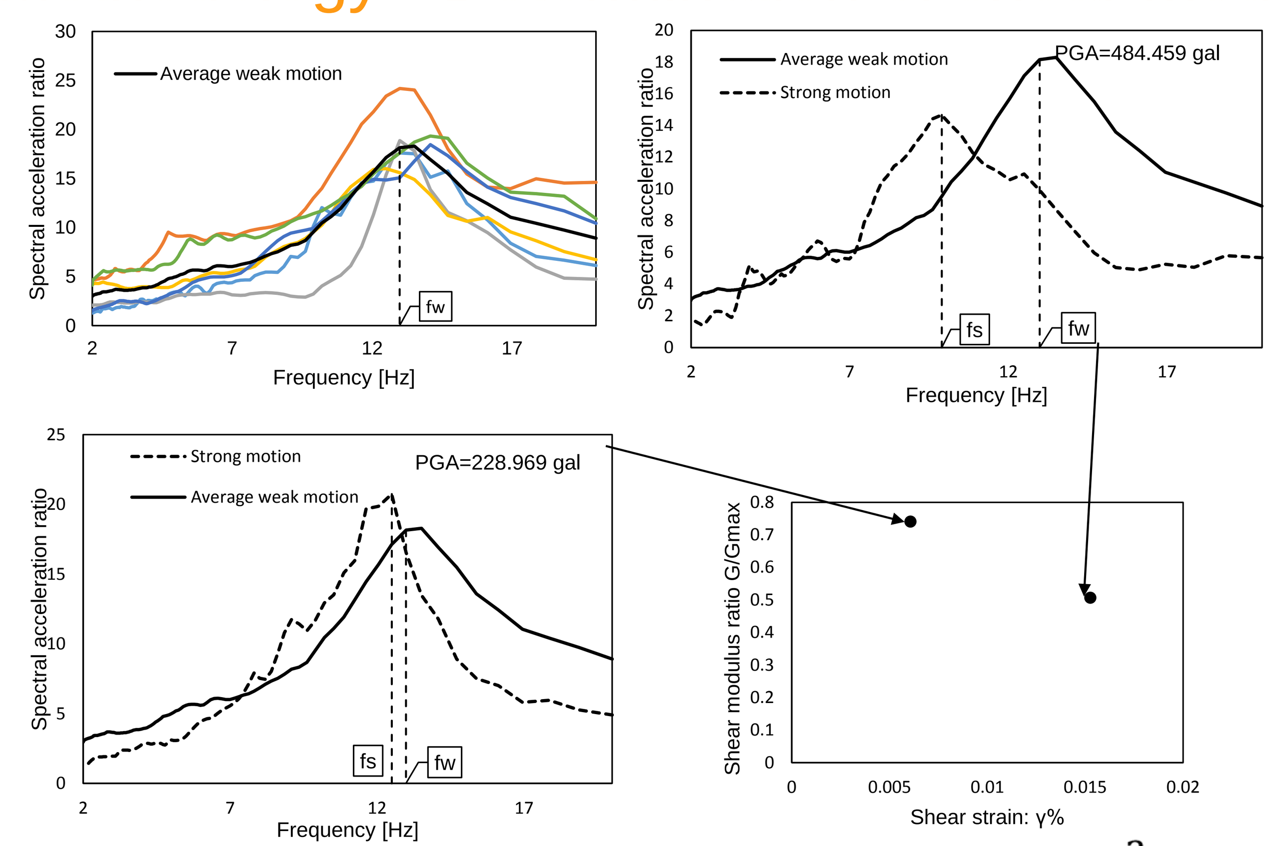
After the Kobe earthquake on January 17, 1995, NIED decided to improve the Japanese seismic observation systems by installing numerous numbers of strong-motion seismographs covering the whole Japan. KiK-net (Kiban-Kyoshin network) was constructed under the plan, which is a strong-motion seismograph network consisting of pairs of strong-motion seismographs installed both on the ground surface and the at the bottom of boreholes, deployed at approximately 700 locations nationwide. KiK-net is an open data network, strong-motion records are readily available through internet. The geological information, velocity profiles, and figures for the peak ground motions for most of the observation stations are also available. (Aoi et al., 2004)

Methodology - Determination of fundamental frequency



Horizontal ground response recorded by KiK-net monitoring system is first imported into the software called *SeismoSignal* to produce an acceleration-time history. Then, the time history is converted to an elastic response spectrum. The normalised spectral acceleration between the ground surface and the bottom of the borehole is the transfer function. The peak frequency of the transfer function is the required fundamental frequency.

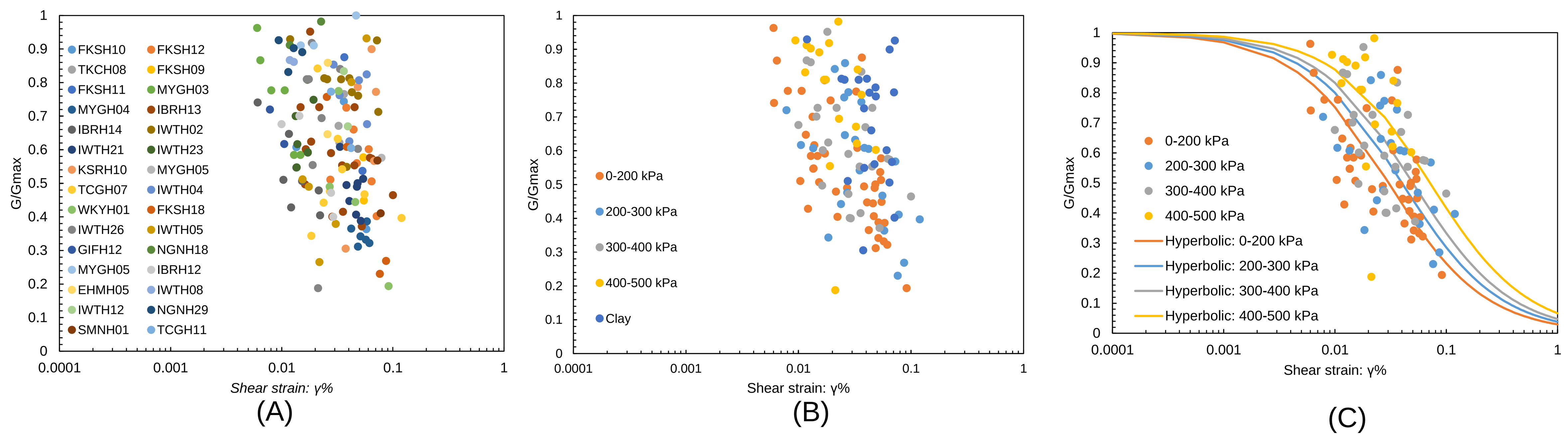
Methodology - Determination of shear modulus



$$\frac{G}{G_{max}} = \left(\frac{f_s}{f_w}\right)^2$$

The reduction in peak frequencies is one of the indications of possible soil nonlinearity subjected to cyclic loading. Based on the 1-D site response analysis, the fundamental frequencies of the soil deposits are related to the shear moduli. The normalised shear modulus is obtained by comparing the response amplification spectra subjected to strong motions with those subjected to weak motions. In this project, motions with PGA greater than 400 gal are defined as strong motions, while motions with PGA less than 100 gal are defined as weak motions. The weak-motion response amplification spectra of each site is the average of those from 6 randomly selected weak motions.

Strain-dependant shear modulus degradation



(A) Seismic data from 30 KiK-net stations are analysed following the proposed methodology, in terms of the strain-dependent shear modulus degradation.
(B) Classification based on different confining pressure levels and soils (i.e. gravelly soil and clay).
(C) Best-fit curves based on hyperbolic degradation model.

- The shape of the shear modulus degradation curves is influenced by confining pressures
- Stiffness for gravelly soils degrades more rapidly with decreasing confining pressures
- Cohesive soils stay elastic for larger deformation levels
- Empirical relation between stiffness degradation and shear strain levels based on the hyperbolic model:

$$\frac{G_{sec}}{G_{max}} = \frac{1}{1 + (36.4 - 0.045) \cdot \gamma}$$

References

Aoi, S., Kunugi, T. & Fujiwara, H. (2004) Strong-motion seismograph network operated by NIED: K-NET and KiK-net. *Journal of Japan Association for Earthquake Engineering* 4 (3), 65-74.

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