

The impact of seasonal rainfall toward crustal pore pressure: Insight from seismic velocity change monitoring

Rezki Dewi Andajani¹, Takeshi Tsuji^{1,2}, Fernando Lawrens Hutapea¹

¹Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University

²International Institute for Carbon-Neutral Energy Research, Kyushu University

Email: rezkiadewiandajani90@mine.kyushu-u.ac.jp

Abstract: Pore pressure can be seasonally time-variant depending on surface perturbations. Pore pressure conditions can be evaluated from the changes in seismic velocity. This study focuses on the response of crustal pressure from seismic velocity monitoring during a rainy season in the Chugoku-Shikoku region, Japan. We computed the cross-correlation between rainfall and seismic velocity change. We discovered that the correlation between rainfall and seismic velocity changes is mostly negative. The inverse relationship infers high pore pressure (velocity decrease) condition in the deep formation, due to groundwater level fluctuation. Such fluctuations are caused by aquifer recharges from rainfall. Moreover, time-lag information further implies the near-surface layer's permeability that controls the water percolation reaching the water table. We concluded that the lithology above and below groundwater contributes to the crustal pore pressure variations related to the seasonal rainfall.

Keywords: pore pressure, seismic velocity changes, rainfall precipitation, lithology.

1. INTRODUCTION

Pore pressure is one of the most critical parameters characterizing crustal dynamics. Under high pore pressure conditions, any fluctuations in pore pressure generate cracks [1, 2]. Since pore pressure changes affect seismic wave propagation in the earth's crust, several studies have been applied to estimate seismic velocity changes [2, 3, 4]. Several studies reported that seismic velocity changes are seasonally influenced by rainfall precipitation [5,6]. Such variations could reflect seasonal changes in pore pressure. Since the fluid flow in porous rock is the primary influence of pore pressure change, we aim to investigate the relationship between seismic velocity changes and rainfall infiltration. Here, we investigate the relationship between rainfall and seismic velocity data monitoring changes in the Chugoku-Shikoku regions. In order to assess the impact of rainfall on seismic velocity changes more accurately, we applied a band-pass filter and computed the cross-correlation between the time series data.

For stations with high correlation coefficients, we observed mostly a negative relationship between seismic velocity and rainfall changes. At the same time, rainfall is known to directly recharge an unconfined aquifer. The negative correlation indicates the high pore pressure in the formation below groundwater due to overburden pressure. The result of the time-lag further implies the permeability of the unsaturated zone in the aquifer. We conclude that the seasonal variations of pore pressure related to seasonal rainfall are also influenced by the lithology of near-surface and in the deep formation, below the groundwater.

2. DATA AND METHODS

We analyzed the seismic velocity change, rainfall, and sea-level changes obtained in the Chugoku-Shikoku region from 2015 to 2017. We used the seismic velocity change calculated from the stretching interpolation method [2]. We used a frequency range of 0.1-09 Hz, reflecting the depth resolution within the surface - 8 km. Seismic velocity change was measured between the main

station and its pairs. To obtain seismic velocity change at each station, we applied a spatial averaging of the pair stations within a radius <40 km from the main station. We also averaged rainfall data from all meteorological stations within a radius of 40 km of the main seismic station.

In the Chugoku-Shikoku region, the intensity of snow cover is minimal; thus, it can be negligible. Surface water mass is known to influence crustal deformation [7]; at some stations, seismic velocity change exhibit variations reflecting the seasonal sea-level rise [6]. To minimize the effects of ocean perturbations, we applied a band-pass filter to all data-set. We used periodic bands when the correlation coefficient between rainfall and sea-level changes can be suppressed. Using the band-pass filtered time-series, we computed the cross-correlation between rainfall and seismic velocity changes. In our case, we defined seismic velocity change as the reference trace. We considered only the positive time as we focused on the indication where seismic velocity is influenced by rainfall precipitation. Finally, we show the correlation coefficient and the time lag map in the result section (Fig. 1).

3. RESULTS AND DISCUSSION

Fig. 1 shows the correlation coefficient and time lag results of the cross-correlation analysis. Some stations display positive and negative correlation coefficients. The relatively high correlation (> 0.2) between rainfall and velocity changes was mostly negative (Fig. 1a). In this study, we only consider stations with negative correlations where it represents high pore pressure conditions. The time lag information is significant only if there is a relatively high correlation coefficient. We included only stations with an absolute negative correlation greater than 0.2 (Fig. 1b and 1c).

It has been discussed that the ground surface variations could be reflected in a deep confined aquifer [8]. We compared the seismic velocity change and rainfall precipitation with the closest groundwater level data. We observed that seismic velocity change decreases not too

long after rainfall increases the groundwater level. We interpret decreasing seismic velocity changes due to overburden pressure induced by groundwater level fluctuation. As the overburden pressure increases, the pore pressure in a deep formation will be subjected to vertical stress. If the fluid is trapped inside a low permeability rock, a negative correlation will occur. The fluid that is filling the pore space cannot escape (undrained conditions), resulting in high pore pressure conditions. Conversely, a positive correlation occurs if the rock has sufficient permeability to allow fluid to diffuse as the rock is subjected to stress.

The time-lag result in Fig. 1c further implies the near-surface lithology. High permeability rocks will allow rainfall to reach water-table in a relatively short period. Time-lag result can also be an indicator of the fractured consolidated rocks (e.g., igneous and crystalline rock) which also produces secondary permeability that could allow rainfall percolation from the surface.

4. SUMMARY

Based on the observed changes in the seismic velocity, the status of pore pressure associated with rainfall can be predicted. The negative correlation indicates high pore pressure conditions in deep formation due to overburden pressure. The time lag results show that rainfall penetrates the water surface due to the permeability of the crust. It can be concluded that the lithology above and below groundwater contribute to changes in crustal pore pressure during seasonal rainfall.

ACKNOWLEDGMENT

The seismic data (Hi-net) were obtained from the National Research Institute for Earth Science and Disaster Resilience. The rainfall and sea-level changes data were obtained from the Japan Meteorological Agency. We are fully grateful for the support provided by the Kyushu University, Advanced Program in Global Strategy for Green Asia.

REFERENCES

- [1] Tsuji, T., Tokuyama, H., Costa Pisani, P., Moore, G., Effective stress and pore pressure in the Nankai accretionary prism off the Muroto Peninsula, southwestern Japan. *J. Geophys. Res. Solid Earth* 113, 2008, 1–19.
- [2] Nimiya, H., Ikeda, T., Tsuji, T., Spatial and temporal seismic velocity changes on Kyushu Island during the 2016 Kumamoto earthquake. *Sci. Adv.* 3, 2017
- [3] Brenguier, F., Rivet, D., Obermann, A., Nakata, N., Boué, P., Lecocq, T., Campillo, M., Shapiro, N., 4-D noise-based seismology at volcanoes: Ongoing efforts and perspectives. *J. Volcanol. Geotherm. Res.* 321, 2016, 182–195.
- [4] Ikeda, T., Tsuji, T., Temporal change in seismic velocity associated with an offshore MW 5.9 Off-Mie earthquake in the Nankai subduction zone from ambient noise cross-correlation. *Prog. Earth Planet. Sci.* 5, 2018.
- [5] Rivet, D., Brenguier, F., Cappa, F., Improved detection of preeruptive seismic velocity drops at the Piton de la Fournaise volcano. *Geophys. Res. Lett.*, 2015
- [6] Wang, Q.Y., Brenguier, F., Campillo, M., Lecointre, A., Takeda, T., Aoki, Y., Seasonal Crustal Seismic Velocity Changes Throughout Japan. *J. Geophys. Res. Solid Earth* 122, 2017, 7987–8002.
- [7] van Dam, T., Blewitt, G., Larson, K.M., Lavalee, D., Milly, P.C.D., Shmakin, A.B., Wahr, J.M., Crustal displacements due to continental water loading. *Geophys. Res. Lett.* 28, 2001, 651–654.
- [8] Kamp, G. & Maathuis, H., Annual fluctuations of groundwater levels as a result of loading by surface moisture. *J. Hydrol.* 127, 1991, 137–152.

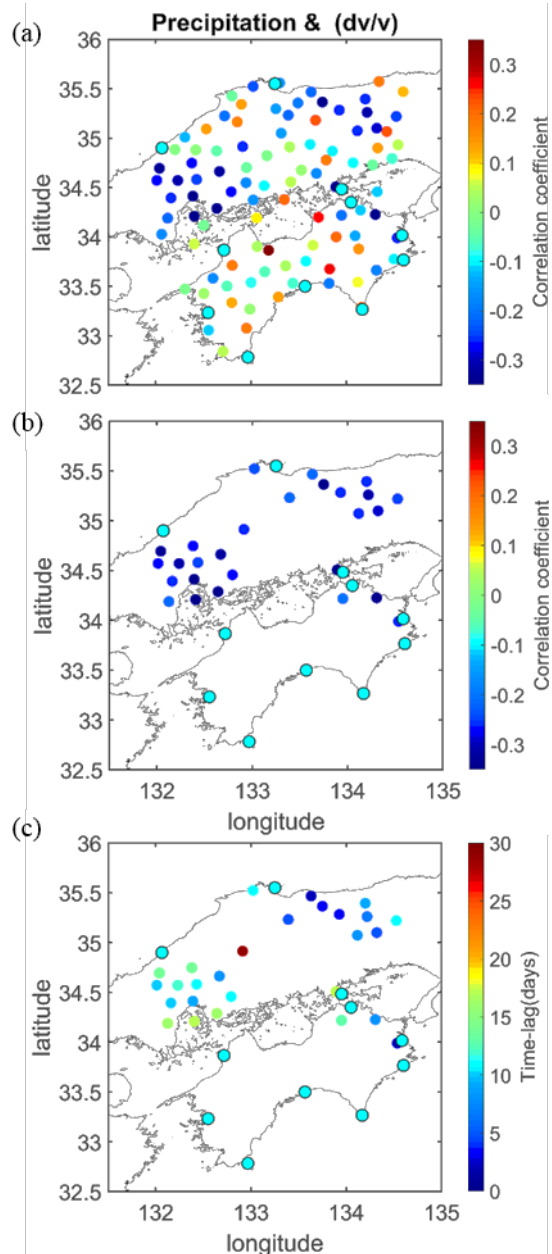


Fig. 1. The correlation between rainfall precipitation and seismic velocity change (dv/v). (a) Correlation map for all stations. (b) Correlation map considering absolute negative correlation coefficient > 0.2 . (c) Time-lag result obtained from panel (b).