**[Project summary]**

## Long-term Research Visit (Project No.: 2021L-03)

Project title: Application of Diffuse-Field Theory for Velocity Inversion of K-Net Stations by J-SHIS Data and a Telescopic Evolutionary Algorithm (TEA)

Principal Investigator: Iman Ashayeri

Affiliation: Razi University, Kermanshah, Iran

Name of DPRI CP (contact person): Prof. Hiroshi Kawase

Research period: visiting period August 12 ~ September 17 2022

Research location: DPRI, Kyoto University

Number of participants in the collaborative research: (DPRI:2 non-DPRI: )

- Number of graduate students: (Masters: Doctoral students: ) (Included number)
- Participation role of graduate students [ ]

Anticipated impact on research and education

A new inversion algorithm for shear wave velocity of subsurface structure was developed and examined in 7 K-NET/KiK-net stations.

(1) Research report

The project was performed on 8 strong motion stations in Japan (K-NET and KiK-net) and 3 strong motion stations in Iran (ISMN). It was aimed to, firstly develop a new eHVSR inversion algorithm for ground velocity structure based on diffuse wave-field concept (DFC) presented by Kawase et al. (2011), and secondly investigate the application of the new algorithm and DFC for the tectonic region of Iran.

(2) Summary of research progress

With respect to pandemic conditions of COVID-19 throughout the world, the PI was able to visit DPRI, and Kyoto University in August 2022 (from 12 August to 17 September). Hence, some parts of the research were performed remotely, and the rest were handled during the visit. In the first part, almost a full investigation was performed for the seven stations of K-NET and KiK-net. A summary of the results are presented in the attached project report, and more details were presented in a publication by Ashayeri et al. (2023).

As for the second part and during the visiting period, the newly developed code was validated for another KiK-net station and applied to three Iran strong motion stations (ISMN). A summary of the results are presented in the attached project report, and another manuscript was prepared that is under review at Earth, Planets and Space journal.

Accordingly, the goals of the project were achieved.

(3) Summary of research findings

The authors would like to highlight the remarks of their study as followings.

• The new inversion algorithm solves the problem of velocity inversion with verified and stable results and adequate flexibility of performing precise and costly or rough and fast analyses.

• The new inversion algorithm is able to provide reasonable velocity profiles from eHVSR down to the seismic bedrock that is more important for the identification of deep-bedrock subsurface structures.

• The new inversion algorithm can be used as a tool to retrieve important site proxies for strong motion stations that will help future investigations on seismic microzonation and development of site specific design spectra.

• The new inversion algorithm was examined to be applicable for the velocity inversions at sites with wide range of geological conditions as long as we have three components of seismic motion data along with suitable geological and borehole data.

(4) Publications of research findings

Iman Ashayeri, Fumiaki Nagashima, Hiroshi Kawase, Mohammad Torabi Dashti,
Application of a telescopic evolutionary algorithm with the diffuse-field concept for velocity inversion from strong motion data at K-NET and KiK-net stations in the presence of borehole and geological data,
Soil Dynamics and Earthquake Engineering,
Volume 164,
2023,
107528,
ISSN 0267-7261,
https://doi.org/10.1016/j.soildyn.2022.107528.

# Application of Diffuse-Field Theory for Velocity Inversion of K-Net Stations by J-SHIS Data and a Telescopic Evolutionary Algorithm (TEA)【Long-term Research Visit 2021L-03】

*Iman Ashayeri*
Assc. Prof. Razi University, Iran.

*Hiroshi Kawase*
Program-Specific Professor of Disaster Prevention Research Institute (DPRI), Kyoto University.

*Fumiaki Nagashima*
Assc. Prof. DPRI, Kyoto University.

**Introduction**

A geophysical analysis of observed strong motions provides insight into the ground structure that is essentially needed for the earthquake risk identification of populated and/or industrial cities. This research will investigate the strong motion records at selected sites of K-Net/KiK-net stations and applies a newly developed algorithm for ground structure identification based on diffuse-field concept (Kawase et al. 2011).

The new evolutionary algorithm that is named telescopic evolutionary algorithm (TEA), is developed for the inversion of the spectral ratio of the horizontal to vertical components of the strong motions (eHVSR), based on the diffuse-field concept (DFC). We verified TEA by the synthetic eHVSR curves from the literature, and examine its convergence stability with respect to the independent variables of the algorithm. Furthermore, this study presents application of TEA in the inversion of eHVSR curves for the shear wave velocity of the subsurface structure down to the seismic bedrock at seven stations of K-NET/KiK-net strong motion networks in Japan. In the course of this study, the corresponding geological maps of the regions from Geological Survey of Japan (GSJ) as well as the site condition database of K-NET/KiK-net, and Japan Seismic Hazard Information Station (J-SHIS), are processed. Afterward, TEA is applied to retrieve Vs profiles of the subsurface structures at these stations, in order to highlight the performance of TEA at various geological settings. Moreover, we compared the results of the new code of TEA with the existing one that is hybrid heuristic search (HHS) for a KiK-net (IBRH11), and 3 Iran Strong Motion Network (ISMN).

Seven stations of this study are in Hokkaido (HKD073), Miyagi (MYG001, MYG006, MYG014), Chiba (CHB001, CHBH14), and Gunma (GNM016) prefectures (Fig. 1). Figure 2 presents the location of the three ISMN stations (KRD, SLS, and SPZ).

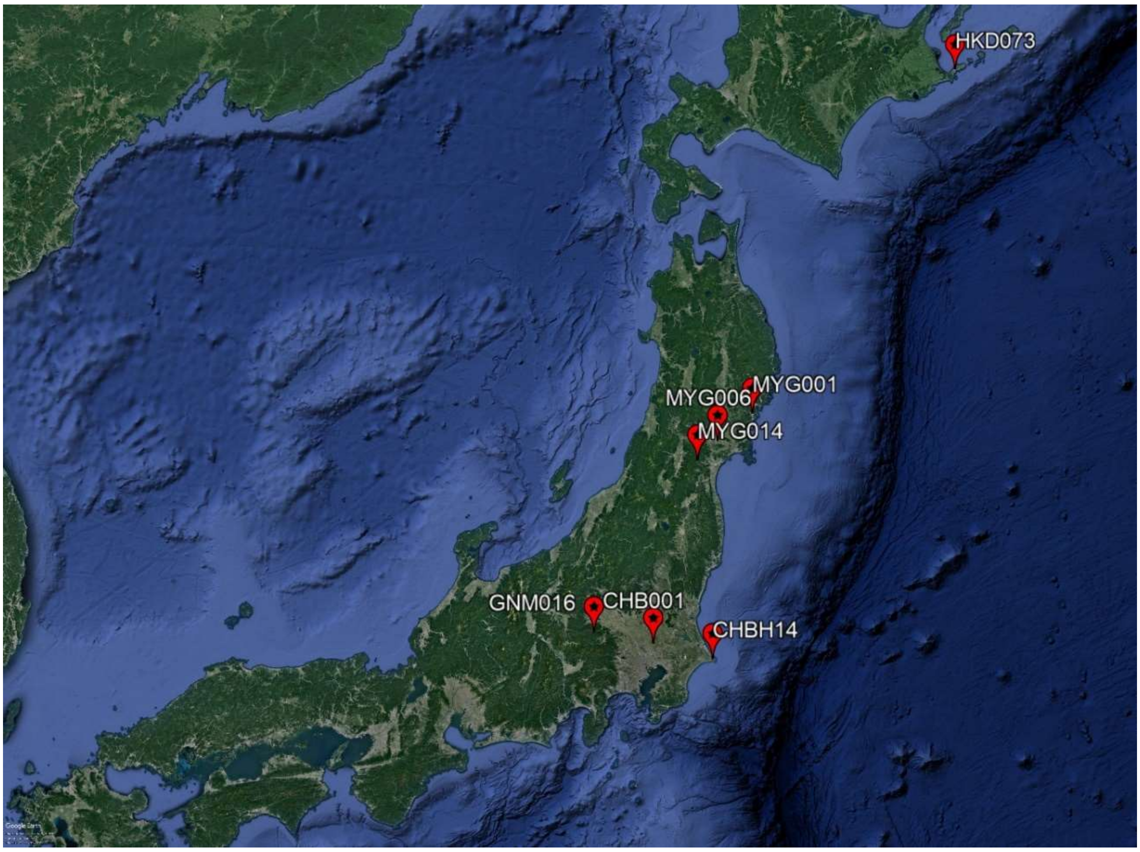


Fig. 1, The location for the K-NET and KiK-net stations of this study

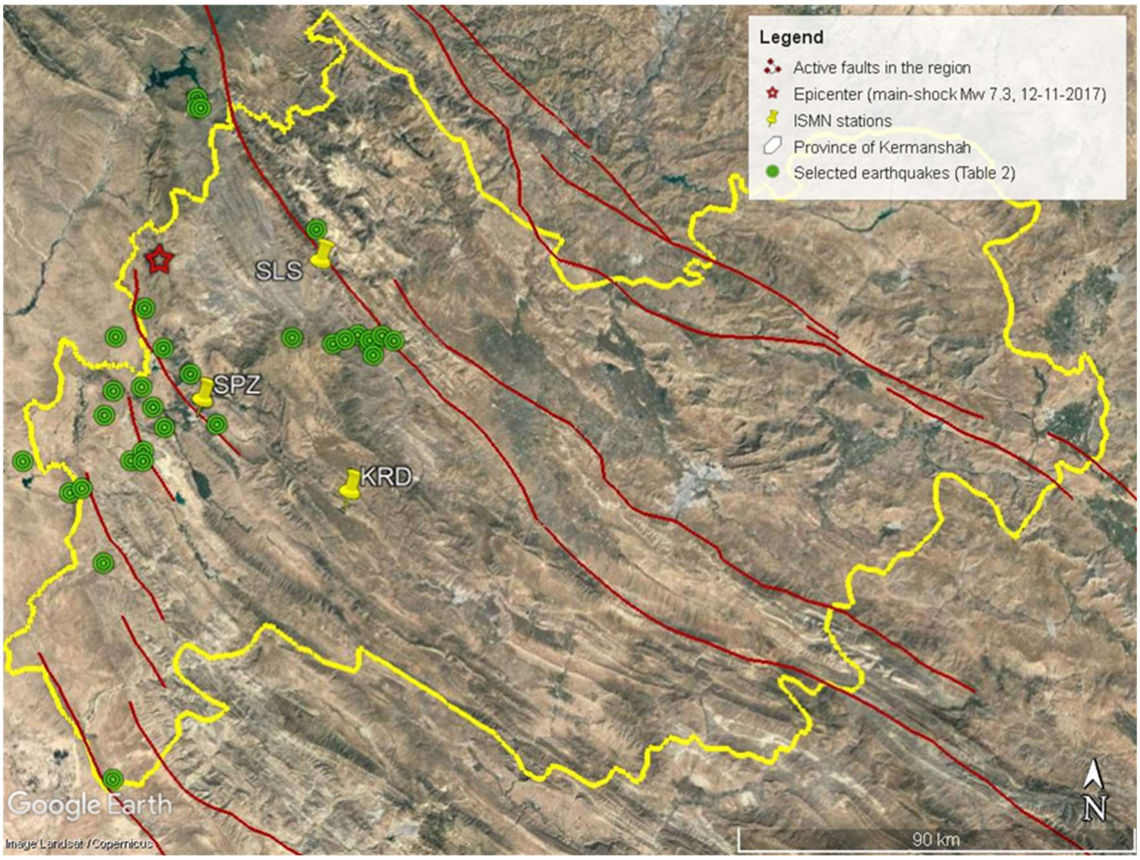


Fig. 2, The location of 3 ISMN stations in Kermanshah, Iran

The project investigates the following aims.

a) Calibration of J-SHIS' maps of subsurface structure at selected stations.

b) Evaluate the 2D site structure by observing inversion of eHVSR at two directions (i.e., NS/UD and EW/UD) by the application of TEA.

c) Comparing TEA and Hybrid Heuristic Search (HHS) at some of the selected stations.

d) Presenting important site proxies from the retrieved subsurface structures at the stations.

e) Examining application of DFC and inversion of eHVSR at tectonic of Iran for the first time.

**Summary of research findings**

The authors would like to highlight the following remarks of this study:

• TEA is a new algorithm for solving the problem of velocity inversion with verified and stable results and adequate flexibility to perform precise and fast analyses.

• The TEA can provide reasonable velocity profiles from the eHVSR down to the seismic bedrock, which is more important for the identification of deep-bedrock subsurface structures. The inversion scheme must be applied to seismic bedrock. However, in the case where there is no significant power at low frequencies representing the deep structure, the solution of the TEA must be considered a viable solution, unless other sources of reliable information can be provided. This should not be viewed as a weakness of the TEA because no other practical solution can have less uncertainty than the solution given by the TEA based on the eHVSR. Meanwhile, there is no need to reduce the uncertainty of the layers that do not contribute to the significant amplification of the basin.

• TEA can be used as a tool to retrieve important site proxies for strong-motion stations, which will help future investigations on seismic microzonation and the development of site-specific design spectra.

• TEA was observed to be applicable for velocity inversions at sites with a wide range of geological conditions, as long as we had three components of seismic motion data along with suitable geological and borehole data. Yet, we must acknowledge that the velocity structure retrieved by any inversion technique is non-unique by nature and therefore we must pay proper attention to any independent source of information on the structure above the seismological bedrock.

In this study, we investigated three ISMN's stations (i.e., KRD, SLS, SPZ) that are close to the epicenter of a recent and large earthquake event of November 12, 2017 Mw 7.3 in Iran. A KiK-net station (IBRH11) was studied as a benchmark, too. We performed comparisons of the only two existing velocity structure inversion computer codes based on DFC for earthquakes i.e., Nagashima et al. (2014) and Ashayeri et al. (2023). The benchmark of IBRH11 showed that the codes are identical in their theoretical eHVSR calculation. The results provide reliable velocity structures for the ISMN stations of this study from the ground level to the seismological bedrock that were not available previously (see the $V_S$ profiles in Fig 3). The codes of Nagashima et al. (2014) and Ashayeri et al. (2023a) could provide physically meaningful and consistent velocity structures for the ISMN stations. Furthermore, this study provided the $V_S$ structure corresponding to the nonlinear response of KRD and SPZ from the main-shock eHVSR, which represented frequency shift to lower values and amplification or de-amplification by the soil nonlinearity (see the eHVSR curves in Fig 3). This was also important that showed the successful application of DFC to a single earthquake in the tectonic region of Kermanshah and calculation of the empirical nonlinear site amplification function at these sites.

**Velocity structure above seismological bedrock estimated from earthquake recordings; an application of diffuse wave-field concept to strong motions in Iran**

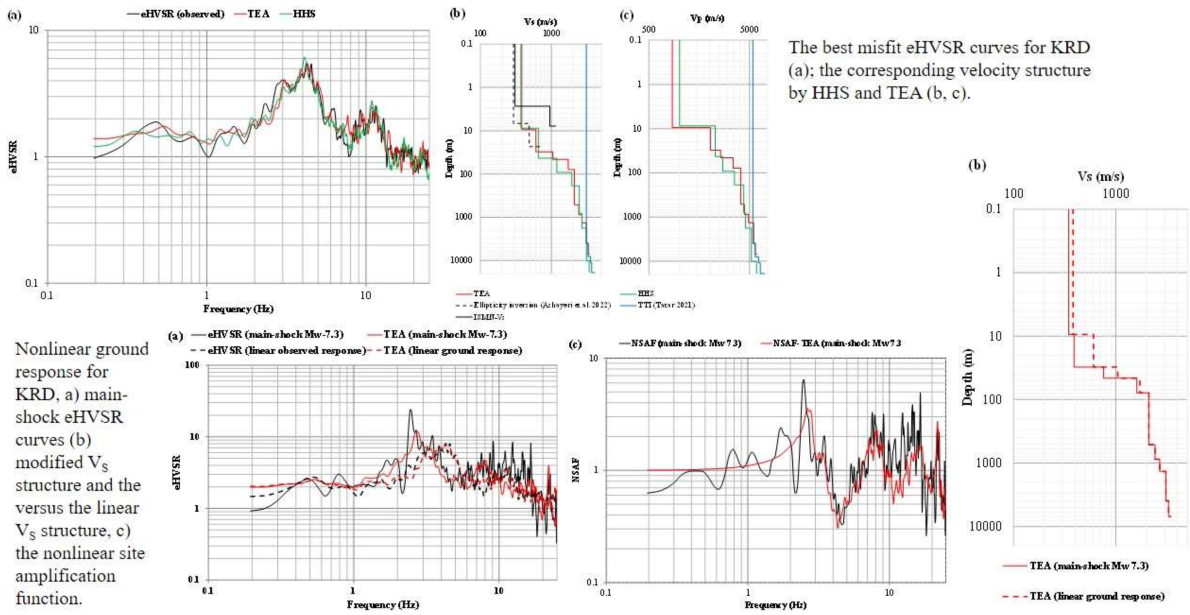


Fig. 3, The summary of inversion analysis of ISMN stations and the nonlinear eHVSR curve (Ashayeri et al. 2023b)

**References**

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