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Data-driven imaging of seismic wave field in the Tokyo metropolitan area based on lasso

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Rapid prediction of damage due to large earthquakes on constructions such as buildings and bridges through a numerical simulation that computes seismic responses of all constructions provides important information for making a decision of priority order relating to rescue and rehabilitation activities without waiting for on-site reports. Such a simulation requires ground motion input to each construction, which usually distributes much denser than seismometers. An estimation of the ground motion should rely on data-driven modeling from observational data because of insufficient information related to hypocenters or underground structure models needed in a numerical simulation of seismic wave propagation.

We propose a new methodology based on lasso (least absolute shrinkage and selection operator) for the purpose of data-driven imaging of seismic wave field in an urban area from seismograms obtained by a dense array. The target of this study is the Tokyo metropolitan area, in which MeSO-net (Metropolitan Seismic Observation network) consisting of 296 accelerometers has been established. We assume that a Taylor's expansion model is capable of estimating the seismic wave field at an arbitrary point from seismograms at nearby observatories. This model is reduced to a multivariate linear regression of which the matrix of predictors is a set of products of positions of the observatories, the outcome matrix consists of the observational data, and the coefficient matrix to be estimated consists of the partial derivative coefficients. The coefficient matrix is estimated by group lasso, which minimizes an evaluation function consisting of a loss function given as the squared discrepancy between the observation data and the regression model, and a regularization term based on the L2 norm for selection of grouped variables. The reason why we implement group lasso rather than ordinary lasso is that it can avoid the dependency of subjective coordinate settings in time and space.

We have applied the proposed method to synthetic seismograms obtained from an analytic solution of seismic wave field assuming that an earthquake of M7 class occurs in a horizontally-layered underground. The resulting image reproduced better than those obtained by other methods such as the ordinary least square, ridge regression, and lasso. We have also applied these methods to the actual MeSO-net data when the 2011 Earthquake off the Pacific coast of Tohoku occurred, and confirmed that group lasso reproduced the actual seismic wave field better than other methods.

Keywords: urban mega earthquake, MeSO-net, sparse modeling, lasso, imaging, regularization