論文の内容の要旨
Abstract of Dissertation

Extraction of Lagrangian Ground Displacements and Subsurface Seismic Stress Changes for Rational Earthquake Disaster Mitigation

（合理的な地震減災に向けての地盤のラグランジアン変位、および地盤内応力場変化の抽出）

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(Abstract)

Earthquakes are catastrophic events instigating a variety of devastations by the strong ground shaking and/or internal deformations of the earth's crust. Although they draw less immediate attention, ground deformations often induce more serious devastations and long lasting geotechnical problems. Estimation of damage caused by an earthquake and to have a deep insight into the source mechanism primarily demands for the strong ground motion records. However, seismic records are either missing or very sparsely available, especially in the developing and third world countries. Therefore an alternate and more practical approach to define mechanisms for different types of damages, induced by seismic events, is a pressing need of the society for effective rehabilitation works, disaster mitigation, land conservation and specifications/guidelines for new constructions.

With the development of the space geodesy technology such as Laser Imaging Detection and Ranging Technology (LIDAR) and Interferometric Synthetic Aperture Radar (InSAR), acquisition of images of landforms and the changes in elevation with high (sub-milliimeteric) precision has become possible. However, normal interferograms detect displacements only in the Eulerian description, in which the description of motion is made in terms of the spatial coordinates which does not follow the motion of soil particles. When InSAR images are taken from different satellite flight directions, the 3-D displacement field of the terrain can be determined but it can still not distinguish the shallower ground displacements from the deeper crustal deformations. A method has been proposed and refined to extract three dimensional Lagrangian ground displacements from the available set of pre- and post-seismic digital elevation models with the underlying assumption that tectonic displacements have a gentle spatial variability. The method is capable of mapping out shallower and localized ground displacements (landslides, manmade changes etc.) from the total ground displacements. Reliability and practicality of the numerical approach was evaluated by its implication to one of the very well recorded and documented seismic event,

the Mid-Niigata Prefecture Earthquake. The outcomes were found very well consistent with the field measurements of benchmarks and triangulation points. Furthermore, the pattern of Lagrangian ground displacements is in strong agreement with earthquake induced devastations.

Following the theory of elastic dislocation, linear geodetic source inversion analysis is carried out, with the available Lagrangian ground displacements, to reveal the source mechanism and spatial distribution of slips on fault rupture planes for Mid-Niigata Prefecture Earthquake and 2005 Kashmir Earthquake. Discontinuities across the rupture planes embedded in laterally homogeneous stratified half-space are extended to obtain internal deformability and seismic stresses/strains in the interior of earth's crust through forward modeling. The second principal invariant of deviatoric stress tensor, J_2, is considered as work-a-round indicator of the rock's vulnerability to failure in the absence of reliable rock failure criterion and spatial coverage of soil/rock properties. Various tunneled sections for Joetsu line of Japan bullet train network (called Joetsu Shinkansen) passing through the epicentral area of Mid-Niigata Prefecture Earthquake were seriously damaged. Both the first invariant of Cauchy stress tensor, I_1, and the second principal invariant of the stress deviator tensor, J_2, are calculated at a regular interval along the longitudinal axes of selected tunnels such that the examined points would also include the damaged sections. Remarkably, all the damaged tunnel sections were found against the peak values of $\sqrt{J_2}$. A yield surface is defined as the boundary between clusters of points for damaged and undamaged tunnel sections in the scatter diagram of I_1 and $\sqrt{J_2}$.

Thousands of landslides were triggered both by Mid-Niigata and Kashmir Earthquakes. All the triggered landslides by both of the aforementioned earthquakes are found concentrated within the area of large seismic stresses/deformability. Furthermore, the landslides which existed before Mid-Niigata Prefecture Earthquake have also shown a strong concordant behavior with the co-seismic stresses which suggests that a similar stress pattern might have been repeating in the past. Therefore, the obtained yield surface can be used to examine the margin of safety of both existing and new tunnels for a given scenario earthquake in the target region as well as for delineating potentially hazardous area for landslides.