論 文 の 内 容 の 要 旨

論文題目　Numerical Simulation of RC Tunnel Junction Component Using High Performance Computing
（ハイパフォーマンスコンピューティングを用いたRCトンネル接合部材の数値シミュレーション）

氏　　名　　孫　方涛

In an urban area, underground structures of more complicated configuration tend to be built. For instance, in Tokyo Metropolitan, two large-scale expressway tunnels which have a merging/diverging ramp tunnel to the ground level are constructed; the junction parts which connect the two main tunnels and the ramp tunnel are a large-scale steel-concrete composite structure with complicated and varying configuration. On the mechanical viewpoint, such a junction is a critical component of the tunnel system because it transfers load between the main tunnels and the ramp tunnel. This component must have highest seismic safety, and intensive experimental studies have been made to quantitatively examine the load capacity. With wide and mature utilization of numerical computation, numerical analysis can be an alternative of experiments; it is able to provide more insights for estimating the load capacity of the tunnel junction. Therefore, the main aim of this thesis is to take advantage of an advanced parallel finite element code, ADVENTURE, to numerically study the nonlinear behaviors of RC tunnel junction components. The nonlinear behavior of concrete is accurately captured by a well validated concrete constitutive relations and a prominent method for failure analysis that uses Particle Discritization Scheme (PDS). These two essential features are implemented into the ADVENTURE program.

The concrete constitutive relation is developed based on experimental observation, and the equations which express the relations are quite complicated. In order to implement this constitutive relation into the ADVENTURE program, we have to reformulate the relations. Furthermore, the concrete constitutive relations yield non-symmetric and non-positive definite elasto-plasticity tensor, which will be a fatal hinge in applying a fast solver which is based on the conjugate gradient method. A suitable algorithm which deals with this non-symmetry and non-positive-definiteness is developed.

PDS is a general scheme of discretizing a function. We have to cast fracture criteria of concrete into the form which is suitable to PDS. The shear and tensile failure criteria are cast in as the form of critical strain, and implemented into ADVENTRUE program.

Verification of the enhanced ADVNETURE program is made, by reproducing experimental results of RC structure members of simple configuration. Stress transfer mechanism between concrete and steel rebar is examined. Although some limitations are found in the current treatment of the interface between concrete and steel, typical features of RC structure behaviors which include failure are reproduced to some extent.

Validation of the enhanced ADVENTURE program is then made, by studying two experimental models of RC tunnel junction components. The first model is a scaled model of simple configuration. An analysis model of 2,218,164 DOF is constructed, based on the CAD data of the model. The macro-scopic behavior of this model is well reproduced by the numerical simulation; for instance, we can obtain a load-displacement relation which agrees well with the experimental observations, with relative errors being less than 10 %. The variability of failure patterns due to cracking is studied by using analysis models of different meshing. It is shown that the variability is not large, suggesting that the mathematical solution of crack paths is stable. The second model is a 1/2 scaled model of complicated configuration, consisting of a curved steel girder and an RC body in which the girder is partially embedded. An analysis model of 8,878,959 DOF is constructed. Due to the limitation of experimental setup, it is not an easy task to set boundary and interface conditions for the model. Making trial-and-error approach, we finally find suitable interface conditions between the steel girder and the RC body, so that the macro-scopic experimental observations are reproduced. The micro-scopic behaviors of the analysis model are compared with the experimental observations in detail. While the accuracy of reproducing the experiment is not high, the numerical results of strain history measured at various locations consistency agree with the observed data.

Our studies demonstrate the applicability of the enhanced program to simulate complex RC structure members of a tunnel junction. The nonlinear response and multiple cracking of RC structures are analyzed by the program, although the accuracy has to be improved. As a largest advantage of numerical analysis, insights into the failure patterns of tunnel junction component are obtained through the simulation of using various models for the crack variability study.