飛来物の高速衝突を受けるコンクリート版の衝撃貫通挙動に関する解析的研究

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論 文 名　：An Analytical Study on the Penetrating Behavior of Concrete Slab Subjected to High Velocity Projectiles
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論　文　内　容　の　要　旨

In recent years, to prevent serious damage from natural disasters such as tornados and volcanic eruptions, the demand for protecting structures against the collision of flying objects is recognized in Japan. In fact, not only in Japan but also in many oversea countries, serious damage of structures by natural disasters are not a rare case due to the influence of global warming. Thus, it becomes very important to predict the impact resistance performance of protective structures against flying objects. In general, in the range of plastic deformation where the infinitesimal deformation theory holds, the prediction of structural failure can be easily done by conventional FEM software. On the other hand, the large deformation with extreme local failure such as penetration, the prediction of them is difficult and the accuracy of FE analysis is not validated well. Therefore, it is desired to develop a meshfree analytical method that can evaluate the penetration performance of reinforced concrete structural members.

In this study, based on the above backgrounds, SPH (Smoothed Particle Hydrodynamics), which is one of the meshfree methods that is suitable for the large deformation and fracture problem of solid body, is adopted and improved it to predict the penetration risk of reinforced concrete slab. This paper is composed of 8 chapters. The outline of each chapter is as follows.

In Chapter 1, it is pointed that the demand of protective structures against flying objects caused by natural disasters and the needs of evaluation method on penetration prevention performance of protective structures. In addition, it is also explained that traditional FEM is less capable to solve problems relating to large deformation with penetration phenomenon, while meshless methods are suitable to this kind of problem.

In Chapter 2, the fundamental concept of SPH that is employed in this study is introduced. Particularly, the analysis procedure of solving mechanical problem of solid body using SPH is explained in detail.

In Chapter 3, the impact response analysis by SPH in this study was described. Especially, impact problem between flying objects (solid body) and structural member (concrete slab) requires adequate contact algorithm, thus pin-ball algorithm that is adopted in this study was explained in detail.

In Chapter 4, Material constitutive laws for concrete and steel in this study was described.

In general, impact response analysis needs appropriate dynamic constitutive law considering strain rate effect. So, the strain rate equations for concrete and steel that employed in this study were introduced in detail.

In Chapter 5, the validity and the accuracy of the proposed SPH analysis in this study was verified by comparing analysis results with a falling weight experiment of the RC beam and a penetration experiment of the concrete slab.

In Chapter 6, the failure mode of concrete slab after penetration and the consumed impulse during the penetration process was investigated. It was confirmed that the increase of flying objects velocity gave the failure mode changes from bending failure to local shear failure. It was also found that during the transition process from bending failure to local shear failure, consumed impulse by penetration increased, however it (consumed impulse by penetration) converged to a certain amount in the case of perforation failure.

In Chapter 7, the consumed impulse during the penetration process of concrete slab was taken as the criterion to judge the penetration limit of the concrete slab. An equation predicting the required impulse to penetrate the concrete slab was proposed, and its accuracy was verified by comparing the results by equation with analysis results and other empirical equations. It was found that the results given by predictive equation matches the analysis results in a good accuracy, and the results by predictive equation falls into a reasonable range compared to other empirical equations. These results indicate that the proposed predictive equation is useful to judge the possibility of penetration risk of a concrete slab subjected to a rigid collision object.

In Chapter 8, the results obtained in this study are summarized and the remaining issues in the future are described.