論 文 の 内 容 の 要 旨

論文題目　MODEL TESTS ON MITIGATION MEASURES OF GROUND DISTORTIONS INDUCED BY SEISMIC LIQUEFACTION
（地震時に液状化した地盤の大変形の軽減技術の模型実験）

氏名　ALAM MD.JAHANGIR

Damage induced by seismic liquefaction to water front structures and consequently distortion of ground behind quay walls and river dikes occurred in the past and in the recent seismic events worldwide. Failure of quay walls and river dikes induces lateral flow on the land side causing extensive damage to buried life lines and infrastructure foundations. Seismic liquefaction is generally known as a phenomenon in which saturated or nearly saturated soil behaves as a very soft material due to generation of excess pore water pressure during earthquakes. Many existing water front structures founded on liquefiable foundation and/or having liquefiable backfill are vulnerable to liquefaction damage in future earthquakes. Mitigation of earth embankment damage was studied by many researchers. Damage of gravity quay walls were also studied extensively. However, a study on mitigation of gravity quay wall is scarce in numbers and not enough to have sufficient confidence on the topic.

This experimental study was designed to investigate different mitigation techniques for earth embankment and quay wall. Earth embankment and quay wall, both of which suffer damage due to liquefaction of foundation soil, were selected in this study. The purpose of this investigation is to identify seismic damage mechanism of earth embankment and caisson quay wall and finally to validate available mitigation techniques for them under dynamic loading.

A centrifuge-testing program was conducted to assess the earthquake performance of two mitigation measures for a liquefiable foundation under an embankment. The new in this test program was the use of non-plastic Tottori silt as liquefiable foundation soil with water as pore fluid. Three separate model tests, an embankment foundation system was studied first without, and then with two different mitigation measures: sheet pile enclosure and densified sand wall under shoulder of embankment. Tests were conducted in a 30g centrifugal acceleration field where the model represented a prototype loose foundation layer of 6 m thickness, and embankment height of 1.5m. The effectiveness of mitigation measure has been evaluated using cyclic stress – strain curves and settlement of foundation soil against Arias intensity plot. Sheet pile enclosure found to be effective to reduce settlement by 47%. Lateral spreading of liquefied sand could be prevented at deeper elevations while lateral spreading at shallow depths could not be prevented by sheet piling at toe. Densified sand wall under shoulder of embankment could also reduce the embankment settlement in the same scale of sheet pile though the mechanism was different.

Mitigation of quay wall was studied in both 1-g shaking table tests and centrifuge model tests. In both kinds of model tests, benchmark model tests without mitigation were followed by those with mitigation models. From 1-g shaking table tests, it was found that quay wall damage or displacements are caused by residual shear deformation of foundation soil. Softening of foundation soil due to excess pore pressure, inertia forces of quay wall, and presence of static shear stress in foundation, all together cause the residual shear deformation of foundation. The inertia force of quay wall and dynamic earth pressure of rubble filter were found to be 180 degrees out of phase with each other throughout the dynamic loading irrespective of backfill liquefaction.

Results of mitigation models tests in 1-g field revealed that no mitigation measure in backfill behind a triangular rubble filter was able to reduce the quay wall damage. However, sheet pile or any kind of soil improvement in the foundation on the sea side can reduce the damage extent of quay wall. An optimum location of sheet pile on the sea side was identified as 0.6H distance away from toe of caisson wall, where H stands for the height of a caisson quay wall. Non-liquefiable foundation soil was found to be most effective to prevent the quay wall damage, provided that quay wall would not slide on a rubble mound. Permeation grouting using silica solution seems to be effective to make non-liquefiable foundation.

Furthermore two series of centrifuge quay wall model tests were performed to investigate some of the mitigation measures. Series A used Nikko silica sand as model soil with D_{50} = 0.5 *mm* and did not consider the effects of rubble mound and rubble filter. Series B used Toyoura sand as the tested material, while crashed gravel having 3.4 mm mean diameter was employed for the rubble mound and the rubble filter. Under 50-G centrifugal field, strong motions with more than 400 Gal acceleration at 2 Hz frequency were applied to all the models. Series A showed that a triangular or square configuration of mitigation piles in backfill, within 0.3H (caisson height =H) distance from the caisson wall, reduces the extent of quay wall damage. Series B showed that sheet pile on the sea side and grouting into foundation could reduce the shear deformation of foundation.

Further centrifugal tests were conducted to mitigate the subsidence of river dike models. Effects of installation of sheet piles or compacted sandy walls under the toe of a dike were investigated. Consequently, it was shown that those walls reduce the magnitude of subsidence of a dike model.

As a conclusion, effects of several kinds of mitigative measures were examined experimentally and compared. As for mitigation for existing structures, grouting under those structures seems to be most appropriate.