Numerical simulation of PBL

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An analytical investigation focusing on the concrete damage progress of the PBL shear connector under the influence of various lateral pressures, employing coupled RBSM and solid FEM model was carried out. The internal failure process was also clarified; the two horizontal cracks occurred near the top of the concrete dowels through the hole of the perforated steel plate, afterward, the two vertical cracks also initiated and propagated along with the shear surface. In a low lateral pressure case, the shear strength was determined by the vertical cracks propagated along with the shear surface. While as the amount of applied lateral pressure was increased, the shear strength of two vertical cracked surfaces was enhanced and the shear strength of the PBL was characterized by the occurrence of the splitting cracks and caused the splitting failure into the side concrete blocks. Moreover, the combined effects of lateral pressures and holes' diameters were also evaluated numerically and it was found that the increase in shear strength was more in large diameter case subjected to high lateral pressure because of the wide compressive regions generated around the concrete dowel.

Keywords: coupled RBSM and solid FEM model ; PBL shear connector ; shear strength ; lateral pressures ; failure mechanism

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1. Research Background

There existed two major investigation techniques or approaches for the shear response evaluation of the PBL, firstly through the experimental studies by conducting model tests and secondly through the numerical analyses using the finite-element method (FEM). On the one hand, most of the past studies were experimental based which evaluated the structural performance of the PBL under various loading conditions and test parameters.

On the other hand, the past numerical simulation studies utilized the finite element analyses mainly focused on capturing the test shear strength and the macroscopic load-displacement response under the influence of several test parameters that affected the shear capacity of the PBL and mostly addressed the shear resistance (deformation, stress contours and strain distributions) of the steel plate. In contrast to focus on steel plate, few simulation studies were conducted aimed at verifying the reproducibility of crack propagation behaviors and the failure modes of concrete. The investigation and understanding regarding the detailed internal failure mechanism are important and essential for establishing rational design methods and reinforcement details. Therefore, it is required to analyze the internal failure behavior of concrete comprehensively using numerical simulation analyses.

2. Flow of the research

The current research aims to investigate the effect of lateral pressures on the shear strength of the PBL shear connector and also highlights the detailed failure process of concrete, especially the internal crack propagation behavior and stress distributions, through simulation analyses, which has not been discussed efficiently in past researches, using coupled Rigid Body Spring Model (RBSM) and the nonlinear solid Finite Element Method (FEM). Furthermore, the current research primarily focuses on determining the shear resistance solely of the PBL shear connector without presenting the comparison related to shear performance for different types of shear connectors. The coupled RBSM and solid FEM model combines the use of 3D-RBSM and the nonlinear solid FEM which was proposed by authors. The 3D-RBSM has been referred as an effective numerical approach for the evaluation of nonlinear fracture behavior of concrete (internal crack initiation, propagation, and orientation), quantitatively. In the current study, firstly, the analytical approach based on coupled RBSM and solid FEM model is presented, then the validation of the numerical model is carried out for the test shear capacities and the failure modes of the PBL shear connector specifically under the influence of the various amounts of the lateral pressures applied to the surrounding concrete of the PBL. After the validation of the numerical model, the detailed internal crack propagation process and the failure mechanism of concrete influenced by the varying amounts of the lateral pressures are highlighted and discussed. Furthermore, the combined effects of the varying lateral pressures and the diameters of the holes on the shear resistance of the PBL shear connector are also evaluated

3. Summary of the research

The current research involves the numerical simulation analyses of the PBL shear connector under the influence of the varying amounts of the lateral pressures applied to the side concrete blocks employing coupled Rigid Body Spring Model (RBSM) and the nonlinear solid Finite Element Method (FEM) model focusing on the damage progress (internal crack propagation behavior and stress distribution) of the concrete. Furthermore, the detailed internal failure mechanism of a single PBL shear connector in the simple push-out test is also revealed, quantitatively. Additionally, the combined effects of the various lateral pressures and the diameters of the holes on the shear capacity of the PBL shear connector are also evaluated. Based on the outcomes of the current research, the conclusions enumerated hereafter are drawn.

The numerical evaluation of the PBL shear connector using coupled RBSM and solid FEM model under simple push-out test was carried out. The validation of the numerical model was confirmed through the numerical simulations for quantitative shear strength evaluation and reproducibility of the failure modes of concrete under the influence of the varying amounts of lateral pressures.

It was confirmed numerically that the shear capacity of the PBL increased and the failure mode changed from shear failure to splitting failure with the increased amounts of lateral pressure, which was the same behaviors with the test investigations.

In low lateral pressure case, the vertical cracks propagated along with the shear surface and the large compressive stresses (σ_y and σ_z) were concentrated only around the concrete dowel region, and the shear strength of PBL shear connector was determined by the shear failure of two cracked surfaces around the edge of the hole in the steel plate.

While in high lateral pressure application case as the amount of the applied lateral pressure was increased, the shear strength of the two vertical cracked surfaces along with the shear surfaces was also enhanced and the splitting cracks propagated in the side concrete blocks perpendicular to the thickness of the perforated steel plate and the large compressive stresses (σ_y and σ_z) were also observed in the concrete dowel region as well as in the side concrete blocks. In high lateral pressure application case, the shear strength of the PBL shear connector was characterized by the occurrence of the splitting cracks in the surrounding concrete blocks.

Numerical evaluation for the combined effects of the lateral pressures and the diameters of the holes revealed that there existed clear combined effect and the increase in the shear strength was more in the large diameter case subjected to high lateral pressure because of the wide compressive regions generated around the concrete dowel region as well as in the side concrete blocks.