ANALYSIS ON SHEAR FAILURE BEHAVIOUR OF PHC-PILE

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ABSTRACT

Shear failure behaviors of Pre-stressed High-strength Concrete Pile were investigated by 3D-RBSM which is a discrete numerical model and can describe crack development accurately. The applicability of 3D-RBSM was confirmed by comparing with test results such as load-displacement relationship, crack development, deformation capacity. Moreover, the effects of shear failure behaviors on axial force, shear span height ratio and confinement pressure was investigated. It was shown that even low confinement pressure such as soil pressure, development of shear crack is restrained and the behavior change to ductile behavior with increasing of the pressure.

Keywords: PHC-Pile, 3D-RBSM, Shear Failure, Confinement Pressure

1. INTRODUCTION

As a foundation structural member, Pre-stressed High-strength Concrete (PHC) pile has been used for various structures such as power plant, bridge, building and so on. Recently, earthquake wave motions in design become larger which is considering the occurrence of big earthquakes, such as Kobe earthquake (1995), East Japan earthquake (2011) in Japan. Therefore, high ductility is required for structure to prevent the fatal damage. The pile is important member to insure the stable condition for whole structure. It is required that the deformation performance of pile depending on a soft layer thickness and the deformation is evaluated, since large soil deformation in a soft layer is predicated under big earthquake wave motion.

The deformation performance of PHC pile including the several phenomenon have been evaluated analytically and experimentally, especially the load carrying capacity and macro behavior have been studied. Kisida, et al., investigated shear strength of PHC-pile with large diameter experimentally and analytical (Kisida et al. 1996), (Kisida et al. 1997), (Yamamoto et al. 1998). In their experimental studies, the effect of pre-stress, a/d ratio, axial force and t/d ratio were investigated. Moreover, they modeled PHC-pile by 3D Finite element method to investigate its maximum loading carrying capacity. By 3D-FEM, Yamamoto, et al., obtained very well corresponding results in macro behaviors such as maximum load carrying capacity and its load-displacement relationship until peak-load. However, the problems are how to realistically

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demonstrate the deformation behaviors, evaluating the post-peak behavior of shear failure considering the several conditions under grounds.

In this study, 3D-Rigid Body Spring Method is used to simulate the shear behaviors of PHC-piles and is compared with experiments results to confirm its applicability. Then, the axial force, shear span height ratio and the confinement pressure are set as parameter to evaluate the load carrying capacity, the deformation performance, the cracking propagation and the failure pattern.

2. OUTLINE OF 3D-RBSM

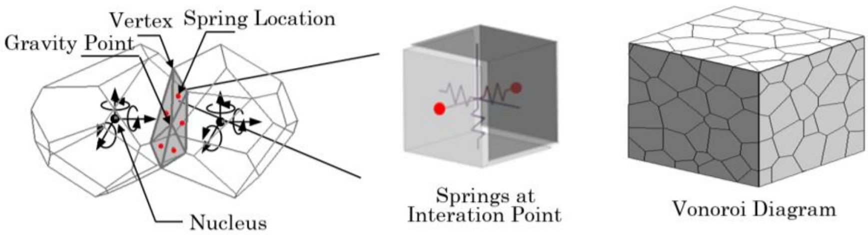


Figure 1: Concept of Rigid-Body Springs Model & Beam Model

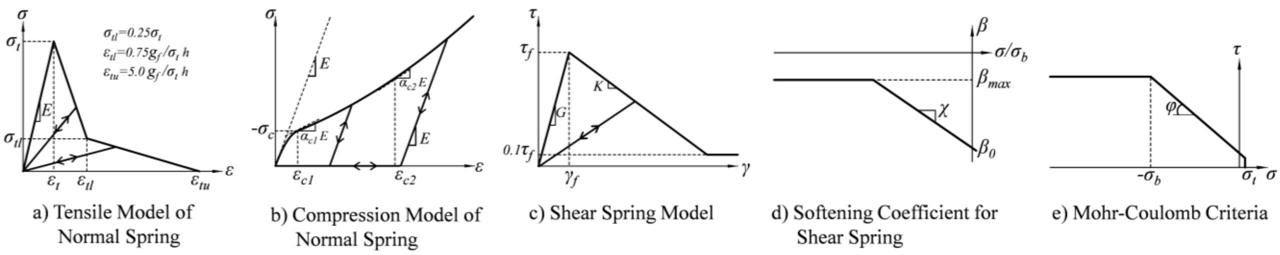


Figure 2: Constitutive Law of Each Spring's in 3D-RBSM

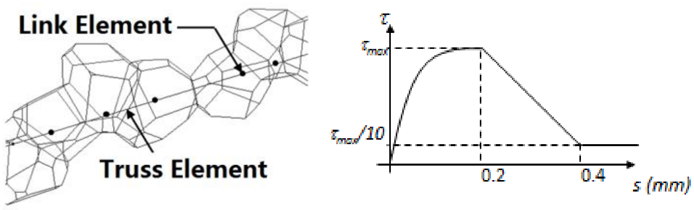


Figure 3: Reinforcement Model and Its Bond-Slip Model in 3D-RBSM

3D-Rigid Body Spring Method (3D-RBSM) is used to analyze in this study. In the model, concrete is modeled as an assemblage of rigid particles interconnected by springs along their boundary surfaces, as showing in Fig.1. The feature of RBSM is that concrete behavior is expressed by deformation of springs between particles and it can show realistic cracking behaviors. The crack pattern is strongly affected by the initial mesh design as the cracks initiating and propagating through the interface boundaries of particles. Therefore, a random geometry of rigid particles is generated by a Voronoi-diagram, which reduces mesh bias on the initiation and propagation of potential cracks. These springs' constitutive laws follow the relationships as Fig.2. The model of each kind of springs is simple one dimension relationship. The applicability of RBSM to concrete material has been confirmed by simulation of concrete cylinder in compressive, tensile and confined condition (Yamamoto et al. 2008).

Reinforcement is modeled as a series of regular beam elements that can be freely located within the structure, regardless of the concrete mesh design. The beam element is attached to the concrete particles by means of zero-size link elements that provide a load-transfer mechanism due to bond effect between the beam node and the concrete particles. Fig.3 shows the element model around reinforcement and its bond-slip model.

3. OUTLINE OF TEST AND COMPARRISON WITH ANALYTICAL RESULTS

3.1. Test Outline

A series of monotonic loading test of PHC-Piles are carried out with different axial force which are -200kN, -100kN, none and +200kN to investigate their mechanic features on shear failure. The dimension of specimens is shown in Fig.4, which has 300mm diameter, 60mm thickness and 450mm shear span (a/d=1.5). High strength concrete (f_c=125Mpa) was used in this test. Regarding reinforcement arrangement, 12 pre-stressing steel bars with 7mm diameter are used as longitudinal reinforcement and pre-stressed of 8MPa is introduced. 100mm pitch spiral stirrups with 4mm diameters are also arranged in specimens.

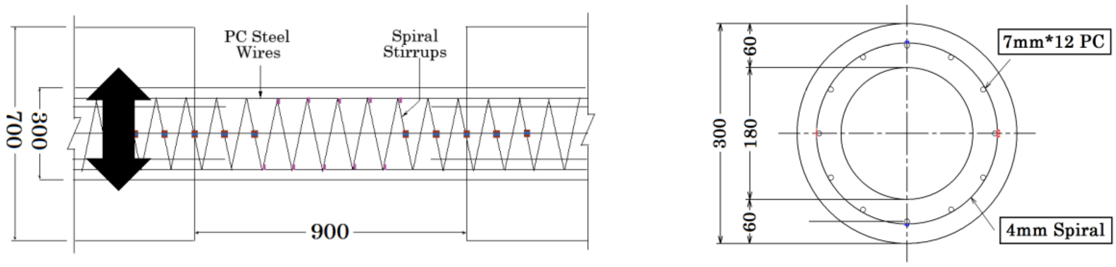
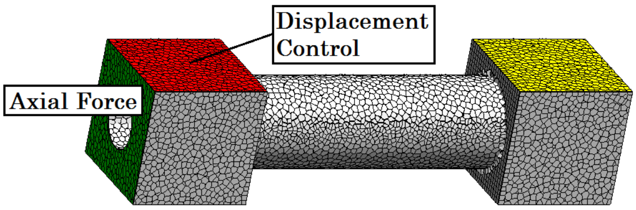
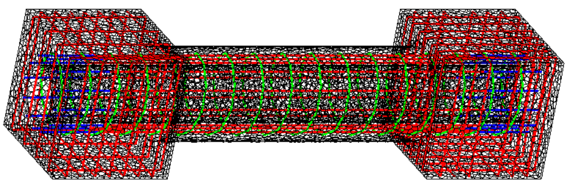


Figure 4: Specimen's Dimension.

3.2. Comparison between Experimental and Analytical Results



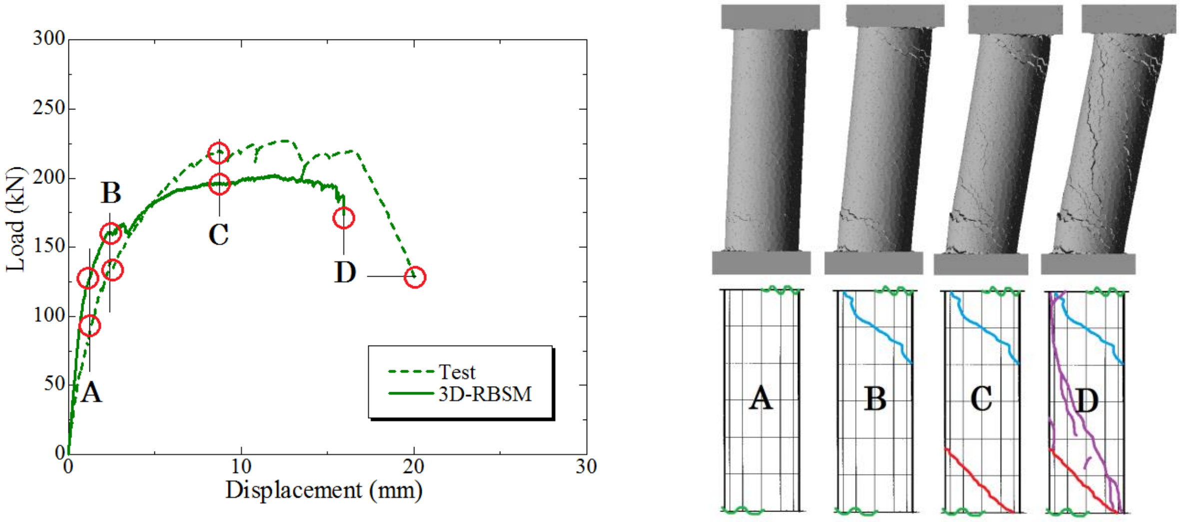
a) Concrete Mesh



b) Reinforcement Arrangement

Figure 5: Specimen's Dimension.

The specimen is modeled as shown in Fig.5, which is meshed by vonoroi-diagram with 20mm size elements. The reinforcement arrangement is shown in Fig.5(b). All reinforcements are modeled by truss element. In the analysis, a stub is fixed all direction as boundary condition, axial force is applied to another stub and the lateral displacement is controlled.

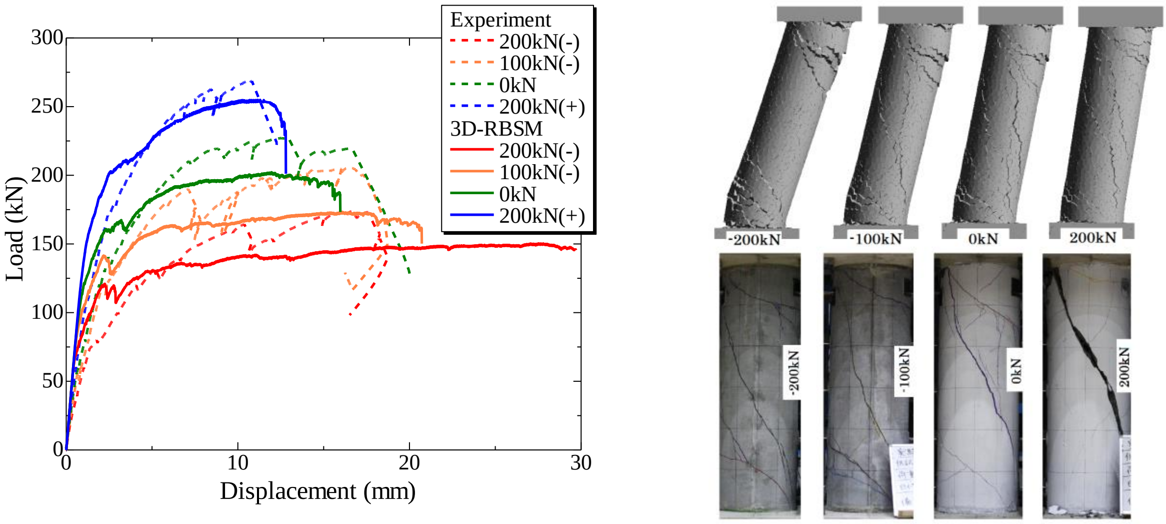


a) Load-Displacement Relationship Comparison b) Crack Development Comparison

Fig.6: Comparison with Process in Test and Numerical of Specimen without Axial Force

The experimental and numerical results without axial force are shown in Fig.6. The load-displacement relationship coincides well from initial to failure stage. Fig.6 (b) shows the deformation and crack pattern at the same displacements of test and analytical results in Fig.6 (a). At point-A, flexural crack initiate at the boundary of stabs. At point-B, the diagonal crack with about 45 degree is observed at an end in test and the diagonal cracks at both ends are observed in analysis due to symmetric condition. The diagonal cracks at both ends propagate at point-C in test and analysis. At point-D, diagonal crack though whole part occur and the load capacity decrease rapidly in test and analysis. All events of test and analytical results coincide well and cracking behaviors obtain form 3D-RBSM show realistic behaviors.

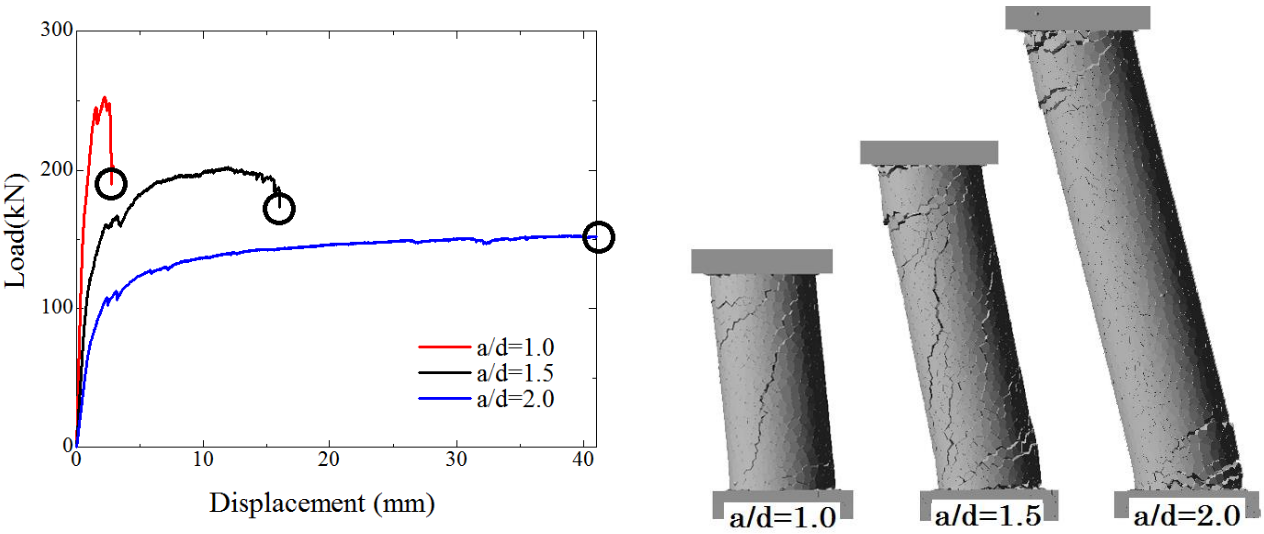
Fig.7 shows the load-displacement relationship for different axial-force cases. The behaviors of PHC-pile are strongly affected by axial force. According to the compressive axial force increase, the load carrying capacity increase and the deformation performance decrease. The results show quite similar behavior with test results. Fig.7 (b) shows crack pattern at final stage which are marked in Fig.7 (a). In the test, the failures occur when the shear crack through whole part is initiate. The shear crack through whole part become dominant and the shear cracks with about 45 degree at the ends do not develop according to the increasing of compressive axial force. The analytical results show same crack development behavior. That is, the shear crack at ends is dominant under tensile axial force, and the shear crack through whole part become dominant according to increase of compressive axial force.



a) Load-Displacement Relationship　　b) Crack Development Comparison

Figure 7: Load-Displacement Curves and Crack patterns in Different Axial Force.

4. EFFECT OF SHEAR SPAN HEIGHT RATIO



a) Load-Displacement Relationship　　b) Crack Development

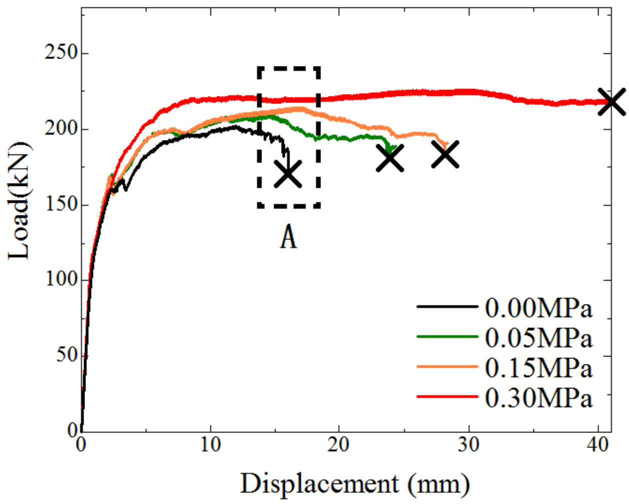
Figure 8: Load-Displacement Curves and Crack pattern in different a/d Ratio.

The deformation behavior of pile in the ground is dominated by the deformation of soil in soft soil layer. In this condition, the deformation performance is more important than its load capacity. Since the deformation performance in soft soil layer is influenced by shear span height ratio (a/d), the effect of a/d ratio is taking into account of this discussion.

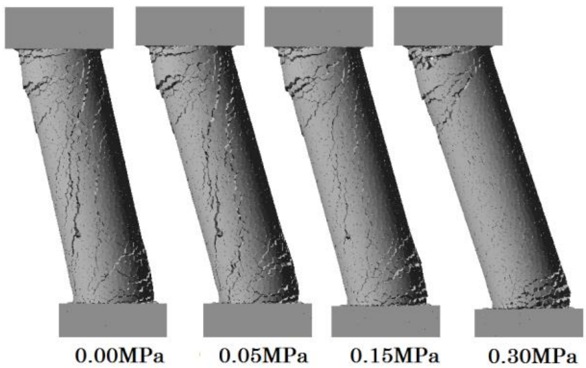
The behavior of PHC-Piles with different a/d ratio is analyzed by using the numerical model without axial force cases and a/d ratios are varied into a/d=1.0 and 2.0. Fig.8 (a) shows the load-displacement relationship with different a/d ratio of 1.0, 1.5 and 2.0. According to the decrease of a/d ratio, the load carrying capacity increase, but the deformation performance remarkable decrease. Moreover, the failure mode also changes from mild flexural failure into sharp shear failure, which is not desirable in seismic performance designing. The final cracks figure in Fig.8 (b) support this tendency. The shear failure turns into dominating according to the decreasing of a/d ratio and the show crack develop through whole part.

5. EFFECT OF LOW CONFINEMENT PRESSURE

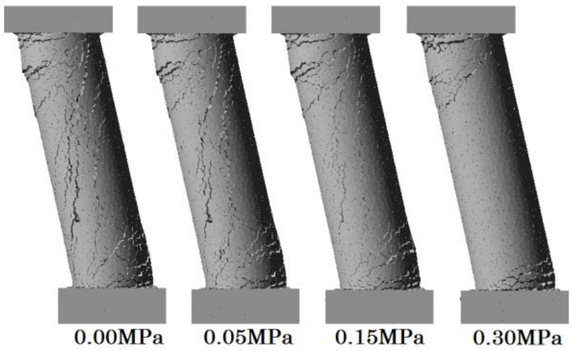
It is reported that the small confinement pressure such as soil pressure has positive effect for ductility of PHC-Pile failed in flexure mode. Imamura et al., investigated the actual behavior of piles, which is expected to show greater ductility than these experimental results in air, because pile embed in the ground are subjected to confining pressure from the subgrade (Imamura et al. 2006). Therefore, the effect of the confinement pressure on shear failure is interesting to discuss about what phenomenon would be caused by confine pressure.



a) L-D Curve with Confinement Pressure



b) Deformation at X-Mark



c) Deformation at A (Same Displacement)

Figure 9: Load-Displacement Curves and Crack Pattern in Different Confinement Pressure.

The PHC-pile without axial force and a/d=1.5 is simulated considering confinement pressure from radius directions. The pressure is only distributed in pile-body surface as 0MPa, 0.05MPa, 0.15MPa and 0.3Mpa. The confinement pressure is distributed perpendicularly to each element's outward surface in the pile-body.

From the load-displacement curve as shown in Fig.9 (a), the deformation capacity remarkably improved by the increasing of confinement pressure and load carrying capacity slightly increase.

Furthermore, from the deformation which is captured at the position with X mark in L-D curve, it is confirmed that shear features of crack pattern are gradually vanished with the increasing of confinement pressure. The sudden failure in shear can be avoided with the increasing confinement pressure. In order to confirm the effect of confinement pressure, deformations at same displacement are compared in Fig.9 (c). The failure behavior has substantially changing. Diagonal shear crack almost disappeared in 0.15MPa case, totally disappeared in 0.3Mpa.

These phenomenon suggest that, PHC-Pile will perform excellent seismic performance over designer's expectation if soil pressure act on pile surface.

6. CONCLUSION

1) A series of experiments and numerical analyses by using 3D-RBSM were carried out in order to investigate the effect of axial force to PHC-Pile failed in shear. 3D-RBSM can simulate the effect of axial force on shear failure accurately and shows realistic cracking behavior. According to the increasing of axial force, the shear crack through whole part becomes dominant and the brittle failure occurs.
2) The effect of a/d ratio was simulated. According to the decreasing of a/d ratio, load carrying capacity increase. However, the deformation performances become quite little which is a potential risk in the ground seismic condition that the dominating factor is not the load carrying capacity but the deformation performance.
3) The effect of low confinement pressure such as soil pressure on shear failure was simulated. Even low pressure around pile body is effective to prevent sudden shear failure and leads the considerable ductile performance.

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