THREE-DIMENSIONAL SIMULATION OF CRACK FORMATION AT ANCHORAGE ZONE WITH MECHANICAL ANCHORAGE

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1. INTRODUCTION

To solve the reinforcement congestion, new anchor system is investigated analytically in this study. The pull-out experiment of reinforcement included mechanical anchorage was carried out by Tadokoro et al[1)] to examine the anchorage performance in thin cover zone. The mechanical anchorage subjected to local stress by anchor plate, is strongly affected the arrangement of anchor plate on anchorage performance. In this study, the 3D RBSM is used to simulate the anchorage failure of mechanical anchorage varied in arrangement. Crack patterns could be simulated similarly to observed in the experiment.

2. ANALYSIS DETAILS

2.1 Analysis method

Simulations were carried out by 3D RBSM (Rigid Body Spring Model). This approach is divided a problem of interest into elements, namely concrete and steel elements. The size of the concrete element is limited to the maximum aggregate size, while the steel element size is set according to the geometry complexity of the reinforcing bar. Three springs (one normal and two shear directions) are set to connect each face of the elements.

2.2 Types and constitutive models of the elements

Two type elements are used to represent the reinforced concrete:

(1) Steel element

To simulate the interlock system between reinforcement and concrete, the geometry of the steel elements is modeled in an accurate manner. The normal and shear springs used in the steel elements are assumed to be perfectly elastic.

(2) Concrete element

The shape of the concrete elements is determined randomly by Voronoi diagram, expect those nearby the steel elements which were set manually following the steel element geometries. The constitutive models between concrete elements are almost same as author's previous research[2)]. In addition to this concrete model, shear strength of the interface between concrete and steel is assumed to decrease according to crack width to represent interface fracture[2)].

3. ANALYSIS CASE

Analysis cases are listed in Table 1, the detail of experimental specimen is shown in Fig. 1, and the analysis model used in the analysis is shown in Fig. 2. Four pull-out tested by Tadokoro et al[1)] are modeled (Fig. 2).On computational time constrains, only 150mm from the top surface of each test specimen is modeled. All case has 4 pull-out longitudinal reinforcements. Case of No.1 has 3 transverse bars in development length, and case No.2 has 6 to investigate the effect of transverse bar on anchorage performance. In case No.3 and No.4, to assume that clear spacing of bars is too small to

Table 1 Analysis cases

Case	Parameter	Ratio of transverse bar p_w	Development length (mm)	Strength of concrete (N/mm^2) Experiment	Analysis Compression (f_c')	Analysis tension (f_t)	Steel Elantic modulus (kN/mm^2)	Number of elements	Maximum load (kN) Analysis	Maximum load (kN) Experiment
No.1	-	0.28	550	26.7	26.7	3.1	190	183,833	865.7	803.0
No.2	Transverse bar	0.57	550	26.4	26.4	3.08	190	177,204	1049.5	951.0
No.3	Arrangement of longitudinal bar	0.28	450, 550	26.9	26.9	3.11	190	233,432	901.0	653.7
No.4	Arrangement of longitudinal bar	0.28	450, 650	26.9	26.9	3.11	190	210,935	959.0	729.9

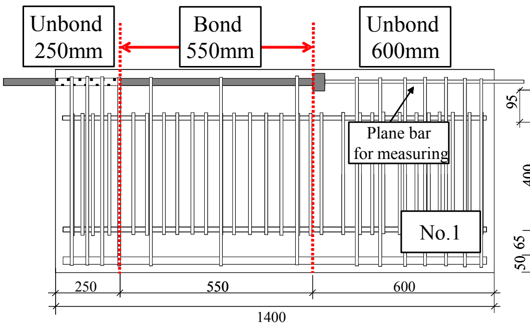

Fig. 1 Experimental set up

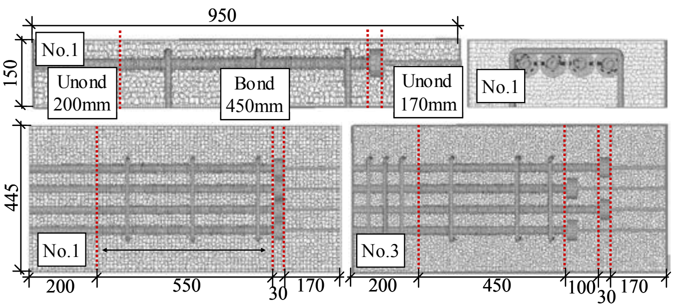

Fig. 2 Analysis model

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place anchor plate side by side, the pull-out bars in longitudinal direction are shifted. Reinforcing bars in specimen model include 25mm deformed longitudinal bars and 13mm plain round bars. The plain bars are assumed analysis for simplifying the modeling process. All longitudinal bars include headed shape anchor which has diameter of 63mm (2.5D, D: diameter of steel bar) at bar end. The boundary condition considered in the analysis is shown in Fig. 3. Monotonically increasing displacement-controlled loading is applied to the steel elements on the loaded end surface, with increment of 0.02mm in 100 steps.

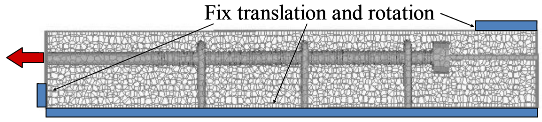
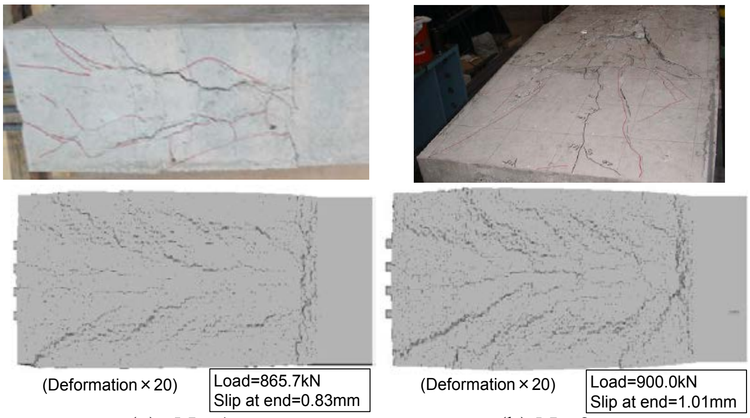


Fig. 3 Boundary condition

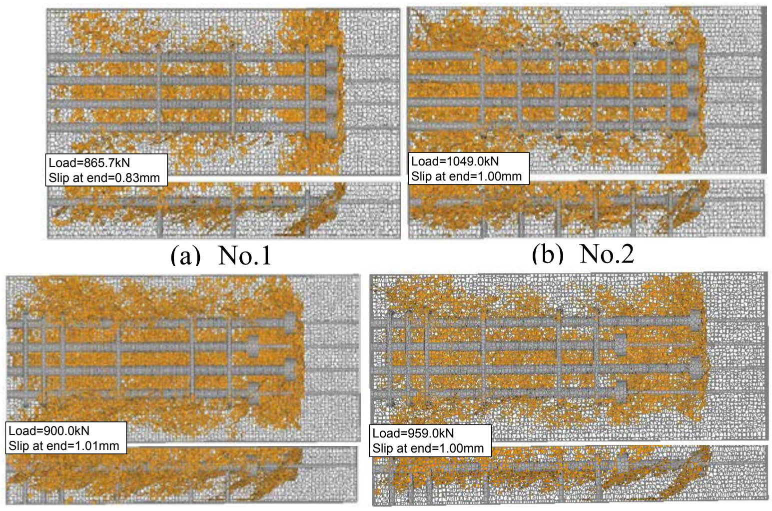
4. ANALYSIS RESULT

The maximum load of experiment and analysis is shown in Table 1, crack pattern of analysis is shown in Fig. 4 with experimental result, and internal crack patterns are shown in Fig. 5. The case of No.1 and No.2 could be predicted the maximum load to compare with experimental one. While in the case of No.3 and No.4, bars are alternately placed, are overestimated. This reason is expected that boundary condition is not appropriate. Because only upper part of specimen is modeled, crack cannot be developed beyond the model thickness. Case No.3 and No.4 was especially governed by fall off of side cover concrete in experiment, but in analysis, side concrete after cracking could resist force by fixing the bottom surface. However, analysis obtained crack patterns replicate the observed patterns well. Case No.1, anchor plate placed side by side, shows the symmetrical crack pattern and crack crossed transversely nearby anchor plates. This transverse crack means that local stress occurred around there. Case No.3, shifted pull-out bar in longitudinally, shows asymmetric crack pattern because of bar arrangement. And transverse crack is formed around anchor plate with rebar of longer development length. Fig.5 shows the patterns of internal crack width of 0.03mm at maximum load. By comparing No.1 and No.2, it is found that case No.1 forms more concentrated cracks near anchor plate. This reason is assumed that the stress at anchor plate increased due to decrease of bond stress in development length caused by less number of transverse reinforcement. From the case No.3 and No.4, it is also confirmed that crack crossed transversely is formed nearby anchor plate with longer development length. One of causes is assumed that restriction by transverse bar near anchor plate with longer development is weaker than other reinforcement.



(a) No.1 (b) No.3

Fig. 4 Crack pattern at failure (Top: EXP, Bottom: ANA)



(a) No.1 (b) No.2 (c) No.3 (d) No.4

Fig. 5 Internal crack pattern

5. CONCLUSIONS

From the results of simulations, following conclusions are made.

(1) RBSM analysis demonstrated that predicted crack patterns replicated the observed patterns well.

(2) From the comparison between cases varied in transverse bar, crack is more concentrated nearby anchor plate in case of fewer transverse bars because bond stress decreases.

(3) From the case shifted reinforcement in longitudinally, crack are concentrated around anchor plate with longer development length.

ACKNOWLEDGEMENTS

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