Size Effect in Out-of-Plane of Column with Side Reinforcement Under Reversed Cyclic Loading

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The investigation in reducing ductility under reversed cyclic loading was studied by experimental work. One column failing in shear mode was tested with highly depth in out-of-plane direction, size effect. The test result used in comparing with finite element programming, so called Wcomd V.1.01.03. Result shown that new prediction in 2-dimensional analysis[1] could cope with 3-dimensional problem and yielded good agreement with testing result by concerning of ductility ratio.

Keywords: column; shear; ductility; size effect; out of plane.

INTRODUCTION

Many researchers tried to achieve great result of 3-dimensions problem by applying 2-dimensional analysis. It is however to different in theoretical background and yield not perfectly results.

It was widely known among researcher that larger of plain concrete smaller of ductility was adopted. The attempt to approach this kind of behavior was proposed in the form of Plain concrete zone, PL, and Reinforced concrete zone, RC.[3] As it was pointed out, however, this method cannot satisfy the 3-dimentional problem[2], for example column presents with side reinforcement.

According to that claim, new prediction in 2-dimensional analysis was proposed by concerning non-linearity of strain distribution in out-of-plane direction.[1] The main conceptual of stating method given that equivalent softening factor can be derived if strain distribution on critical section at failure was known. However, it was reported only in monotonic loading test.

RESEARCH OBJECTIVE

As previously stated, the verification was done by monotonic loading test result, and ambiguous still remains for reversed cyclic loading test. To fulfill the room, newly tested column specimen in the extreme case, which is 60 cm., with presenting side reinforcement was tested. Furthermore, ductility of column, which concerned size effect and subjected to reversed cyclic loading, was compared with ductility from finite element result.

EXPERIMENTAL INVESTIGATION

Fixed-end column specimens with the width, effective depth, and out-of-plane depth, equals to 30 cm., 27 cm., and 60 cm., respectively was tested. The specimen and test layout is shown in Fig.1. Loading point located higher 78 cm. from footing, and deflection was measured at the same height of load.

MATERIALS

Reinforcing bar

Specimen was constructed with D6 and D13 of Grade 345 steel reinforcement and properties shown in Table 1.

Compressive strength

Compressive strength of specimen was used based on cylinder compressive strength test 29 Mpa at 14 day.

Table 1. Reinforcing steel strength.

Bar size	*Fy, Mpa*	*Fu, Mpa*
D6	*391*	*558*
D13	*401*	*586*

TEST PROCEDURE

Statically reversed cyclic load was operated to the specimens. Unloading was controlled by deflection δy, 1δy, and 2δy (δy is deflection that cause yielding in tensile reinforcing bar), in the position of loading. Three cycles of repetition were conducted in each levels of deflection.

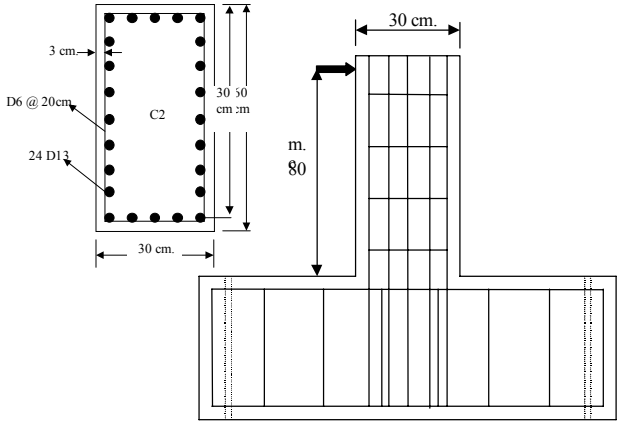

Fig. 1. Specimen cross-section.

FINITE ELEMENT ANALYSIS

The material properties and cross-section described above were used in a finite element analysis program, so called Wcomd. Three cases of mesh generations were model by applying different tension and shear stiffening factor, C. The selected value C=0.8, and C=1.3, originated from proposal[3,1] and supposed case C=1.4. The joint element was used between column and footing connection to simulate the pull out and shear slip. Similar to the test procedure, reversed cyclic was controlled by deflection that cause yielding in tensile reinforcing bar.

RESULT AND DISCUSSION

Column specimen subjected to reversed cyclic load was firstly cracked at load 6 tf, and main reinforcing bars were firstly yielded at 16 tf. The corresponding deflection at yielding load was 4 mm. It was therefore performed 3 cycles, and then increased deflection to be 8mm. At 8mm. of deflection, shear failure suddenly reached as shear crack appeared.

Table. 2. Comparison of Ductility.

Case	δy	δu	δu / δy
Monotonic test result [1]	4	10	2.5
Reversed cyclic test result	4	7.4	1.85
Reversed cyclic C=1.4	4	8	2
Reversed cyclic C=1.3	4	9	2.25
Reversed cyclic C=0.8	4	12	3

Test result was compared with finite element analysis, in each case, as shown in Fig. 2. Structure response of finite element analysis was shown fair agreement with the test result. Ductility of test result and three cases of finite element analysis are also compared and shown above in Table. 2.

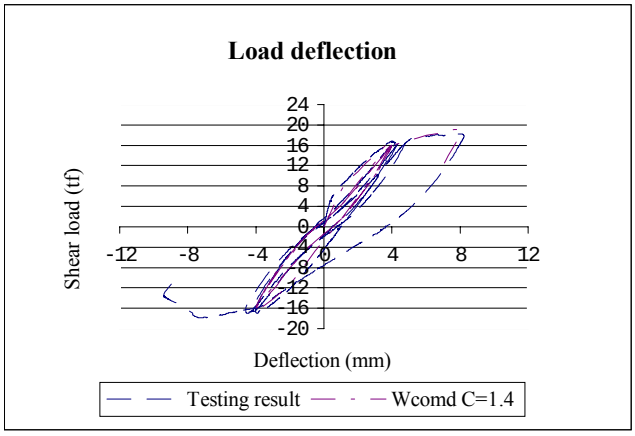

Fig. 2a. Case C=1.4

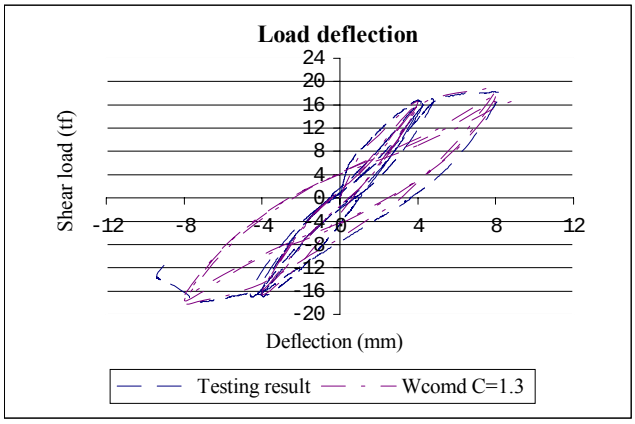

Fig. 2b. Case C=1.3

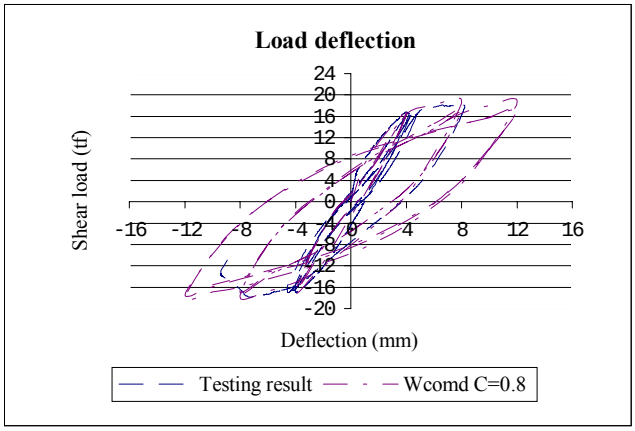

Fig. 2c. Case C=0.8

Fig. 2. Load deflection relationship between test result and Wcomd results.

From the finite element result, it was shown that higher value of tension and shear stiffening factor yielded closer ductility ratio to ductility ratio of reversed cyclic test result. Finite element result illustrated that monotonic loading case has almost similar ductility ratio to reversed cyclic loading case, however, it is too difficult to obtain the same repetition of loading before failure. The cause should root from tension and shear stiffening factor is simulation of effect of concrete zone, size effect, at the ultimate point, but do not capture to actual deformation inside concrete under the complex loading path.

CONCLUSION AND REMARKS

By following the increasing of tension and shear stiffening factor method[1], ductility of column with side reinforcement subjected to size effect and performed under reversed cyclic loading condition can be treated in fair level by finite element program, so called Wcomd.

ACKNOWLEDGEMENT

Author would like to thank Prof. Hiroshi Shima for his helpful comment. Thanks are also extended to Mr. Masaru Ueno for his technical support, and Mr.Thammanoon Denpongpan and Ms. Sachie Kokubo for their help during the experimental phase of the research.

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