The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Field cyclic loading test of a 3-story non-seismically designed existing concrete frame structure in Korea

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ABSTRACT

In this study, lateral load capacity of an existing non-seismically designed concrete frame was investigated through field cyclic loading tests. The frame with 3 stories and 2 bays in loading direction was pushed to the point that strengthdegradationoccurred, and structural failure patterns such as member crack and stiffness-strength degradation were observed in every loading cycle. The test results showed that the stiffness started to degrade when it reached to ultimate strength at the 1.53% drift ratio and the strength degradation was clearly shown after the diagonal shear failure of a central column in second floor. Nonlinear static analysis was performed and its results were compared to the experimental ones.

1. INTRODUCTION

The seismic design codewas first introduced to Korean Building Codeafter 1988 and it began to be applied only for buildings with 6 or more stories. After 2005, the buildings with 3 or more stories began to be seismically designed. Accordingly, most low-rise buildingsin Korea were vulnerable to earthquake loads and theirseismic performancesneed to be evaluated and retrofitted if necessary.

Generally, seismic performance of the existing building structures have been investigated using small-scale building specimens, and most full scale tests are conducted only for a structural member such as column or wall. Furthermore, the specimens were not obtained from a real existing structure and were newly manufactured for the test. Accordingly, full scale test of a real existing structure can provide useful information on exact evaluation of the seismic performance of the existing buildings.Tu (2006) performed the in-site push over test for school buildings in

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Taiwan. They observed lateral strength improvement effect of school buildings with wing walls. Toshimi (2008) conducted a full-scale shaking table test on a three-story reinforced concrete (RC) building.They introduced failure mechanisms with the effects of slip behavior at the base conditions.

The main objective of this study is to investigatelateral load resistance capacity of a non-seismically designed existing 3-story concrete frame through field cyclic loading test.The frame with 3 stories and 2 bays in loading direction was pushed to the point that strengthdegradation occurred, and structural failure patterns such as member crack and stiffness-strength degradation were observed in every loading cycle. Nonlinear static analysis was performed and its results were compared to the experimental ones.

2. DESCRIPTION OF TEST STRUCTURE

2.1 Test Specimen

The test specimen is an apartment buildingstructure which was built in the late 1970’s and located in Gwangju, Korea. Its structural system is 3-story reinforced concrete moment frame and it was designed only for gravity loads.Fig. 1 shows its plan and test setup.Housing unit hasplan of 10.2m(two 5.1m bays) by 7.1m and two stairways of 2.8m by 7.1m are located between the housing units. The story height is 2.8m and slab thickness is 0.2m.In order to evaluate the seismic performance of concrete frame itself, partition walls, exterior walls and floor heating system were demolished.The average compressive strength of the concrete collected in field was 16MPa, and the tensile strength of the steel bar was 250MPa. Fig. 3 shows thesection sizesand steel reinforcement details of beam and column.Outer two units are completely separated from inner two units by demolishing the staircases as shown in Fig.1 and Fig.2, and then the inner two units were reinforced using steel braces and were used as rigid supports for transferring actuator force to outer two units.

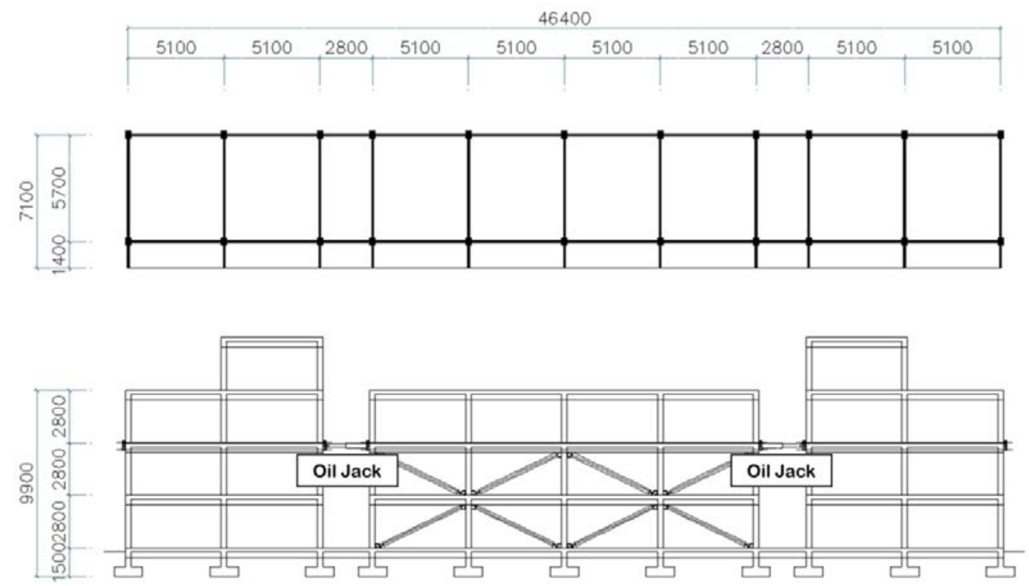

Fig.1Planof the test specimen and Test setup

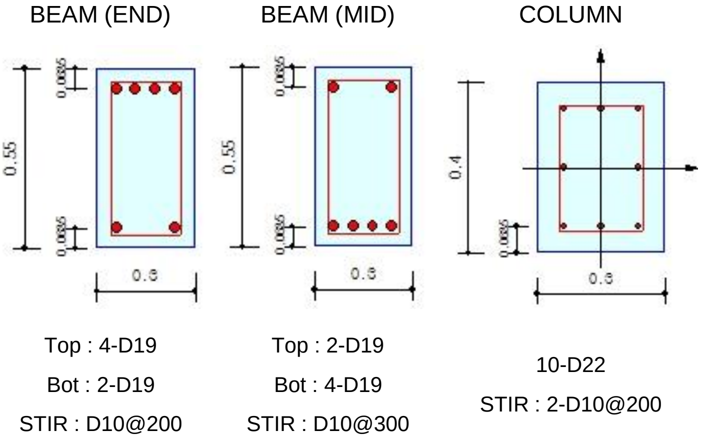

Fig.2Test Specimen   Fig.3 Section size and Reinforcement details

The left end unit in Fig.1 was used as a test specimen for existing bare concrete frame while the right end unit was used as one retrofitted by steel shear wall. The two hydraulic actuators with 0.5m stroke and 200tonf loading capacity were used for this cyclic loading test.

2.2Loading history and Measurement

Generalseismic loading pattern on low-rise building is inverted triangular distribution.Since the resultant force of this distribution is applied to 2/3 point of the building height, the actuators were placed at beam-column connection on the 3rd floor. The actuators were operated based on displacement control. The target drift ratios were 0.2%, 0.35%, 0.5%, 0.75%, 1% 1.5%, and 2%, and each drift ratio was repeated by 3 cycles.

After setting up a reference frame, LVDT sensors were installedbetweenthe reference frame and the 2nd/3rd floors to measure the story drift. And wire LVDT sensors were set in the 1stfloor and the 2ndfloor as shown to measure the inter story drift. Shear deformation and axial strains of the columns on the 1st floor were measured by attaching six strain gages to the central part of the column. Also, as shown in Fig. 5, three LVDT were set in beam-column joint to measure shear deformation of the joint.

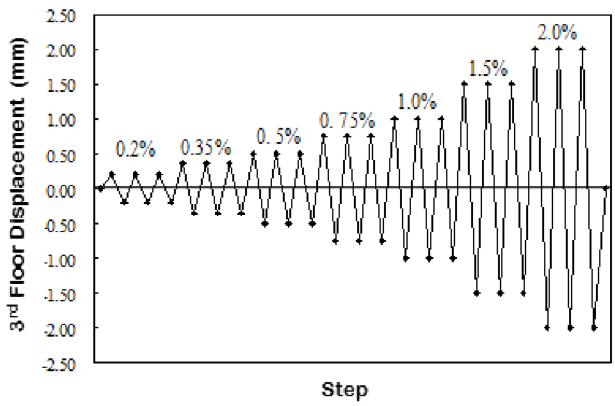

Fig.4Loading plan

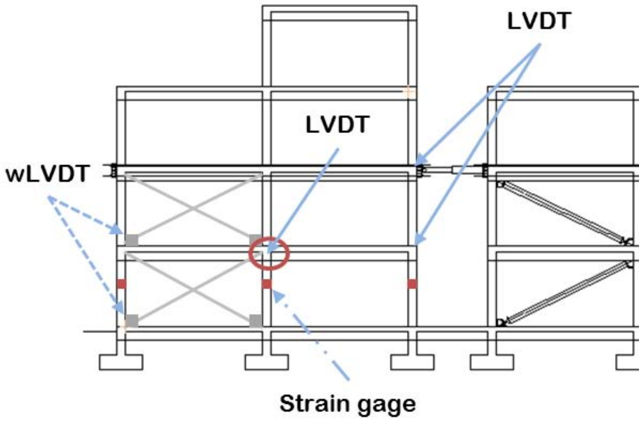

Fig.5 Measurement Sensor Location

3. TEST RESULTS

3.*1* Experimental Push over Curves

Fig.6 shows the force-displacement curvesobtained by cyclic loading test. The force is the resultant of the two actuators. Stiffness decrease was first observed at the0.27% drift ratioand then stiffness degradation rapidlyprogressed to the 0.78% drift ratio. The frame reached to itsultimatestrength at the 1.53% drift ratio,and then the strength started to degrade. After 1 cycle pushed to the 2% drift ratio, the test was terminated due to the risk of entire building collapse.

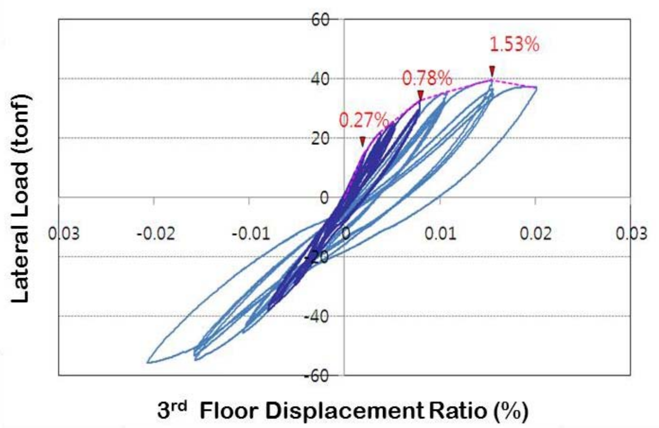

Fig.6Force-displacement curve

3.*2* Failure Pattern

As shown in Fig.7, the first evident failure was observed in exterior beam-column jointof the third floor when the drift ratio reached to 0.78%. Diagonal cracks occurred at the joint and the frame stiffness significantly degraded. And then the diagonal shear failure occurred as shown in Fig.8 in the top of central column on the 2nd floor when the drift ratio reached to 1.53%. After this shear failure, the overall strength of the frame started to decrease.Since the central column is constrained by two beams, the lateral stiffness of the central column is larger than those of outer columns, which resulted in larger shear force in the central columns. Among the two central columns, the column on the 2nd floor has less axial force than one on the 1st floor. This less axial force caused the less shear strength of the column on the second floor while the shear forces applied to the central columns on the 1st and 2nd floors are almost identical under the loading condition used for test.

Fig.7 Crack of exterior beam-column jointFig.8Central columnfailure

4. COMPARISON WITH ANALYTICAL MODEL

Push-over analysis was performed andits results were compared to those from cyclic loading test.Plastic hinge models for beam and column presented by ASCE41-06 were used. The analysis estimated well the initial stiffness and the ultimate strength of the frame while the drift ratio at the ultimate strength was underestimated as shown in Fig.9.

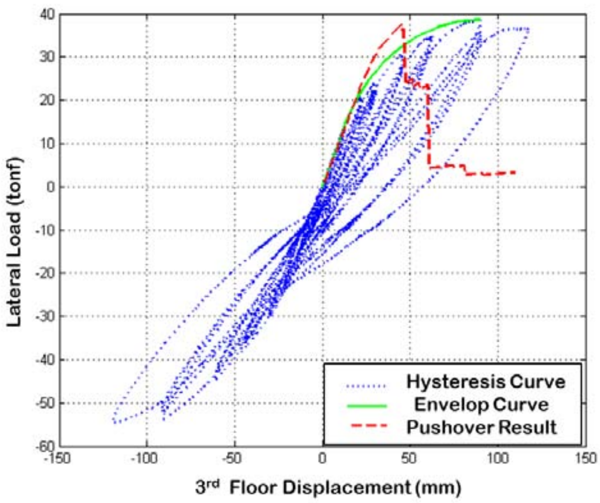

Fig.9Comparison of Analytical and Experimental Results

Fig.10 shows sequence of plastic hinge development in analysis.After the first plastic hinge occurred at the end of beam, failure occurredin the top of central column on the 2ndfloor as the experimental results.This analytical prediction about failure mode of frame corresponds with the test results thatfailure occurredinthe central column on the 2ndfloor which is subjectedto the maximum shear force and the minimum axial load.

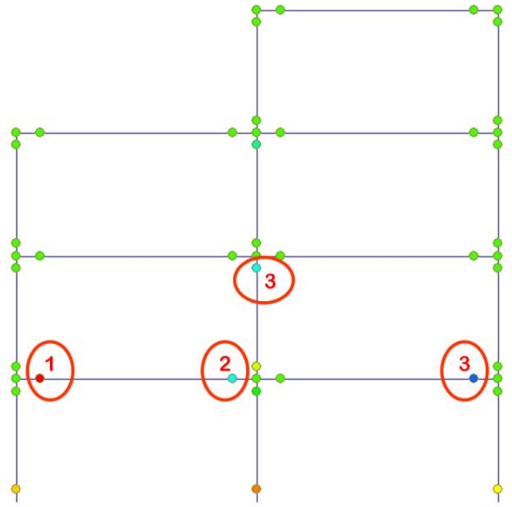

Fig.10Sequence of Plastic hinge Development

CONCLUSION

Lateral load resistance capacity of an existing non-seismically designed concrete frame was investigated through field cyclic loading tests. The test results showed that the stiffness started to degrade when it reached to ultimate strength at the 1.53% drift ratio and the strength degradation was clearly shown after the diagonal shear failure of a central column in second floor.Nonlinear staticanalysis estimated well the initial stiffness, the ultimate strength of the frame and strength degradation failure induced by plastic strain at central column on the 2nd floor.

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