Ultimate Deformation of Seismic Retrofitted RC Piers using Continuous Fiber Sheet with Large Fracturing Strain

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1. Introduction

During earthquakes, RC columns in bridges and buildings are subjected to cyclic lateral loads, generally coexisting with axial load. Failures of these columns mainly can be due to insufficiency in shear strength and ductility. Many researches have been done to improve ductility and shear strengthening, one of them is the application of RC column jacketing using fiber continuous material such as Aramid and Carbon. Column jacketing using fiber material can produce confinement effect to member thus improving the ductility of the member and adding shear capacity of member. However the present known material have small fracturing strain which often become a direct cause of the ultimate deformation.

Improving ductility of structure has been a necessity for structure under earthquake load. Polyethylene Terephthalate (PET), a high fracturing strain fiber material normally used in Japan for soft drink bottles, has recently been researched for RC column jacketing. Recent researches done in Hokkaido University regarding the RC column jacketing using PET indicated that PET is less likely to fracture before column reaches its ultimate deformation due to its high fracturing strain. In contrast to column jacketing using Aramid and Carbon where fracture of the fiber often occurs. This clearly shows that to reach large ductility higher deformability of the material is needed. Unlike lack of stiffness that can be solved by adding more material, lack of deformability cannot be solved just by adding more material.

Shear strengthening has also been a major factor to maintain structure performance due to large lateral load during earthquake. The insufficient amount of transverse reinforcement renders structure member ineffective at dissipating seismic energy and the inadequate ductility rapidly leads to failure. RC concrete jacketing can provide confinement effect due to dilation of member and improve the shear strength of member. Even though PET has low stiffness, adding more plies of PET on confinement can solve this problem.

2. Research Significance

Knowledge of PET column jacketing characteristics under seismic load is an essential factor to have a better understanding of ultimate ductility and shear capacity enhancement of RC column retrofitted using PET and to proposed a new design concept for RC column jacketing using high fracturing strain fiber material

3. Experimental Program

Total 9 specimens, parts of a total 15 RC columns experiment, were retrofitted using PET fiber in plastic hinge area and subjected to cyclic loading with constant axial load 1 MPa with displacement increment 1Δy and one cyclic load for each displacement level. Specimens were tested until ultimate deformation of the specimens was reached. The experiment variables were shear span to depth, column size, ratio of shear capacity to flexural capacity and amount of PET fiber. Figure 1 and 2 shows the experiment setup and applied cyclic load respectively.

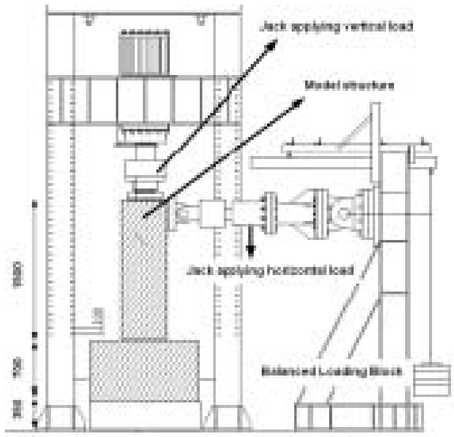

Fig1. Experiment setup

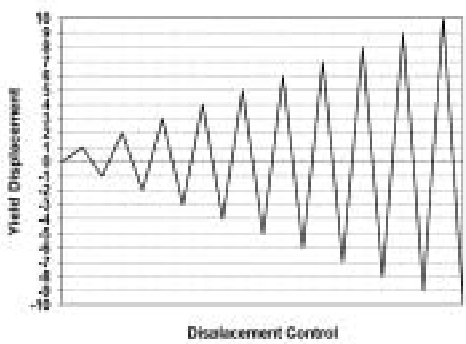

Fig 2. Applied cyclic load

Keywords: column jacketing, ductility, shear strengthening, PET, high fracturing strain, seismic load

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Table 1. Specimen data

Item		SP 5	SP 6	SP 7	SP 8	SP 9	SP 10	SP 11	SP 12	SP 13	SP 14
Dimension	mm	400 x 400						600 x 600			
shear span	mm	1150	1500					2200		1650	
Shear Span ratio		3.1	4					4		3	
ratio of flexural strength to shear strength beyond plastic hinge		0.8	1.05			0.93	1.3	1.13		0.79	0.63
ratio of flexural strength to shear strength at plastic hinge		1.11	1.32	1.18	1.05	1.15	1.47	1.7	1.42	1.26	1.3
Ductility cal		6.7	5.9			5	6.7	6.5		7	6.4
Ductility exp		6.8	8	6.9	6.3	7.6	10.1	7.9	7.5	7.37	4.3

4. Experiment Result

As it can be seen from Table 1, PET confinement on RC column could give large ductility and the value of ductility is larger than expected from JSCE ductility calculation, which is normally used for Aramid and Carbon. The ultimate deformation is mainly reached not due to the fracture of the PET fiber but mainly due to concrete crashing and buckling of longitudinal reinforcement. The PET jacketing on the RC column are supposed to enhance the performance of the structure. However it is noticed in the experiment that even though shear strength calculated according to JSCE code is bigger than flexural strength, SP 7 shows a more ductile behavior compared to SP 14. This shows that JSCE code could not calculate the exact shear capacity enhancement of the structure and these ratio values can not be used as reliable parameter to determine the performance of PET jacketing RC column. Other thing to be noted is that PET jacketing does not give any contribution before flexural yielding, therefore for specimens without enough steel reinforcements, shear crack is prominent during early stage even though there is PET confinement. The evidence of shear crack decreases the concrete stiffness, thus limiting the ductility. Such results can be seen from SP 5, 13 and 14, however for those specimens ductile behavior can be seen and sudden failure due to shear can be avoided.

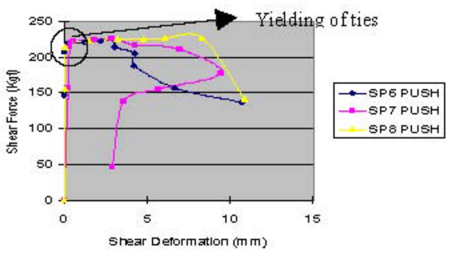

Fig 3. Shear deformation envelope

RC column subjects to cyclic loading may have lost its confinement due to yielding of tie reinforcement, which leads to larger shear deformation and limit the ductility. Experimental result showed that PET application in plastic hinge gave confinement to the column thus limiting the shear deformation to occur. As it can be seen from Fig 3, the growth of shear displacement after yielding of ties can be held for specimens with PET confinement (SP6 and SP 7) while the control specimen (SP 8) shows large shear deformation after yielding of ties.

Ultimate deformation for specimen confined with PET can be divided into two cases. First, specimens with enough shear reinforcement (SP6-SP12) show flexural dominant failure mainly due to negative slope caused by buckling of longitudinal reinforcement and reached the yield strength. Negative slope will begin after maximum load capacity is maintained under several cycles. As for specimens with lack of shear reinforcement and small shear span (SP5, SP13, SP14), ultimate deformation due to extensive shear cracking cause flexural-shear failure. Negative slope will begin right after maximum load capacity is achieved. These two types of failure can be seen in hysteretic loop of the specimens in Fig 4 and Fig 5.

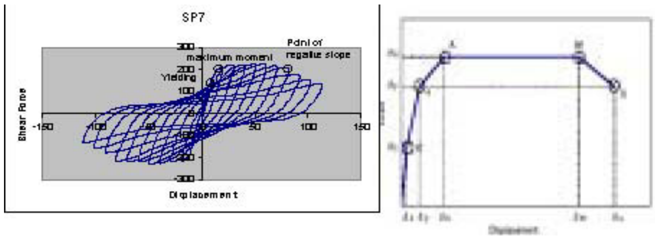

Fig 4. Flexural-dominant failure

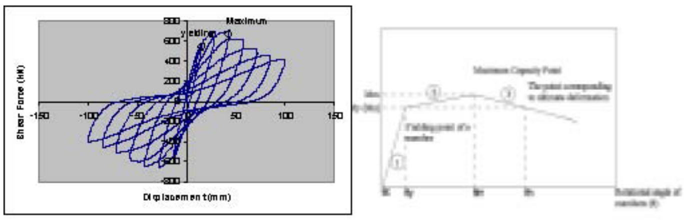

Fig 5. Flexure-shear failure.

5. Conclusion

1. Despite its low stiffness, PET confinement can give enough ductility without significant drop of load carrying capacity
2. Due to its high fracturing strain, fiber fracturing does not occurred until ultimate deformation is reached
3. PET confinement can prevent shear failure for specimen lack of shear reinforcement
4. PET confinement can provide more ductility compared to other fiber material such as Aramid and Carbon
5. The ultimate deformation type of PET confined RC Column depends on the ratio of shear strength to flexural strength before the retrofitting.

6. Reference

Hadiyono, J., Hiroshi, N., Ueda, T., Yasuhiko, S., Dai, J., "Seismic Retrofitting of RC Piers using Continuous Fiber Sheet with Large Fracturing Strain", Journal of Structural Engineering Vol.51A (March 2005), JSCE