

# SEISMIC RETROFIT STUDY OF BRIDGES AT NCREE

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## Abstract

This paper presents the progress of a NCREE's research program on seismic retrofit of existing bridges in Taiwan since 1998. The first phase of studies include testing and analyzing more than sixty large-scale specimens which were designed and constructed to simulate the worst scenario of the construction practice in Taiwan prior to 1987. Twenty-four of the test columns were used as the benchmark for comparison with other specimens retrofitted or repaired using the carbon fiber reinforced plastics (CFRP) jacketing, steel jacketing, and RC jacketing. Experimental results showed that, in general, the retrofit methods used in the U.S. and Japan are effective also effective for the existing RC bridge columns in Taiwan except for the cases of rectangular columns lap spliced at the plastic hinge zone. More research effort is necessary to develop effective methods for RC columns lap-spliced at the plastic hinge zones. Second phase of the study, starting from January 1, 2004, is concerned with the use functional bearing systems to more economically retrofit existing bridges to meet their seismic performance criteria.

## INTRODUCTION

The first phase of a 4-years coordinated research effort on seismic retrofit of existing RC bridge columns has been established at the National Center for Research on Earthquake Engineering (NCREE) since 1998. Major objectives of this program are to develop effective seismic retrofit methods of existing bridge columns in Taiwan due to (1) inadequate design strength, (2) inadequate confinement at potential plastic hinge region, (3) inadequate shear strength due to large lateral steel spacing, and (4) lap-splicing in the plastic hinge zone, etc., identified as some the most severe weaknesses of the existing RC bridge columns for seismic hazard.. Observations of the bridge damage during the 1999 Chi-Chi earthquake indicate that many existing bridges in Taiwan are indeed vulnerable to major earthquakes and the coordinated research program conducted at NCREE is necessary and urgent. This coordinated research program includes a master plan administrated by NCREE and seven coordinated projects handled by the investigators from six universities and research institutions. Results of this research program will provide a domestic test database for seismic bridge engineering applications and to provide seismic retrofit guidelines for highway officials in Taiwan.

However, a detailed study of the reconnaissance reports of bridge damages observed in Chi-chi earthquake shows that, however, the percentage of severe damage of bridge piers are relatively small. The majority of damage occurred at the bearings, shear keys, restrainers, expansion joints and abutments, generally referred as the "bearing systems" in this paper. Due to damage to the bearing

systems, the inertial forces of the superstructure are not completely transmitted to the bridge piers, thus reduces the chance of pier damage during a major earthquake.

In order to study the effect of bearing systems of the bridges under earthquake ground motions, the second phase of a three-years coordinated research effort will focus on the newly defined “functional bearing systems”, which, based on the performance-based design concept, will investigate the force transmission mechanisms and acceptable damage sequence of bridges during a major earthquake, and derive a new seismic retrofit strategy using bridge bearing systems.

## **EXPERIMENTAL PROGRAM**

More than 60 large scale specimens were tested in the first phase study, including 24 bench-mark specimens that were designed to represent typical pre- and after 1987 bridge columns in Taiwan. Cross sectional dimensions of the rectangular columns and circular columns are 600mm by 750 mm and 760 mm diameter, respectively, roughly 2/5 scale of the prototype columns. The worst details that may be expected in the existing bridges are assumed in the specimens, such as the double U-shaped transverse reinforcements with large spacing, and the lap-spliced of main reinforcements at the plastic hinge zone. Retrofit techniques used in the specimens include steel jacketing, FRP wrapping, and RC jacketing. In addition, seismic performance of column-foundation connections, beam-column connections as well as the wall type piers are also studied. Details of the test specimens are listed in Tables 1-3. Test results show that all the retrofit measures used in the study are very effective for RC columns with circular cross sections. They are, however, not very effective to the columns with rectangular cross sections without enlarging the cross section into a circular or oval shape. Due to the page limit, only the results of seismic retrofit study on rectangular RC bridge columns using FRP jacket is reported in this paper.

### **RECTANGULAR RC BRIDGE COLUMNS USING FRP JACKET**

#### *Test Specimens*

##### *┆ Flexural failure mode specimens*

These specimens represent the benchmark and the CFRP wrapped, named as BMR2, BMR3, FR1, and FR2 respectively. Specimen FR1 is retrofitted with 4 layers of FRP (0.55 mm) along the whole height.

For specimen FR2, it is retrofitted based on the ductility requirement of 6. This specimen is retrofitted in the plastic hinged zone with 8 layers of FRP (1.1 mm), and the other areas are retrofitted with 2 layers of FRP (0.275 mm).

##### *┆ Lap-spliced failure mode specimens*

These specimens represent the benchmark, CFRP wrapped, and combined steel plate and CFRP, named as BMRL100, FRL100, SFRL100, respectively. For specimen FRL100, one third of the column height (1100 mm) is retrofitted with 8 layers of CFRP (1.1mm), and the other areas are with 4 layers. For specimen SFRL100, steel plates are attached to each column face before wrapping the CFRP. Combining the steel plate, the cross section became a little close to oval-shaped. The curvature of the shape is advantageous for FRP to produce inward confinement stress to prevent bond slip failure.

### ***1 Shear failure mode specimens***

These specimens represent the benchmark and the CFRP wrapped, named as BMRS and FRS, respectively. In order to observe the 'short column effect', the column height is reduced. For specimen FRS, it is retrofitted with 4 layers of FRP (0.55 mm) along the whole height.

## **EXPERIMENTAL RESULTS AND DISCUSSION**

Figs. 1 to 9 show the lateral force and displacement relationships of the specimens. The sequence from top to bottom is BMR2, BMR3, FR1, FR2, BMRL100, FRL100, SFRL100, BMRS, and FRS. It is shown that both displacement ductility and energy dissipation in BMRL100 and BMRS are quite poor. Compared to specimen BMRL100, it can be seen that specimen SFRL100 performs very well. Not only it gets the 7.24 times of the dissipation energy of the specimen BMRL100, but also enhances 6.03 times of the displacement ductility, a value close to the flexural failure mode. This figure demonstrates clearly that this retrofit method has a good potential in seismic retrofit of rectangular RC columns lap-spliced at the plastic hinge zones.

## **CONCLUSIONS**

### ***1 Flexural failure mode***

1. Test results show that failure of the flexural type specimen under larger axial load will result in speeding up the degradation of strength and energy dissipation capacity.
2. Standard hoop arrangements can gain better confinement than the double-U shaped alternation arrangement used in many existing bridges.
3. The retrofit efficiency of force-based design and displacement-based design is nearly the same. The displacement ductility levels of 7 can be reached.

### ***1 Shear failure mode***

1. Brittle shear failure occurs due to insufficient transverse reinforcement spacing.
2. Retrofitted by wrapping FRP shows great performance in improving shear strengths, and transfers the failure mode to flexural-shear type.

### ***1 Lap spliced failure mode***

1. Without enough confinement stress, bond slip occurred between the lap-spliced longitudinal reinforcements and resulted in brittle failure.
2. Applying CFRP directly can't provide enough confinement stress to increase frictional force between the lap spliced longitudinal reinforcements.
3. A new method by attaching steel plates before wrapping FRP shows great potential in increasing the confinement stress and energy dissipate capacity for rectangular RC members. The strength, ductility, and energy dissipation capacity are also greatly improved. Further study is necessary to better understand the mechanism and to determine the critical parameters for retrofit design applications.

## **REFERENCES**

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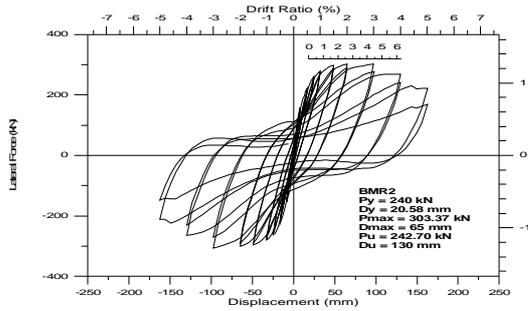


Fig 1 Hysteresis curve of specimen BMR2

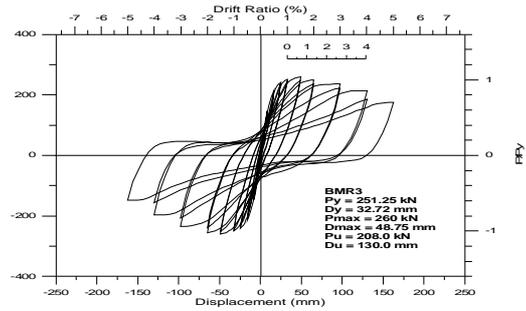


Fig2. Hysteretic curve of specimen BMR3

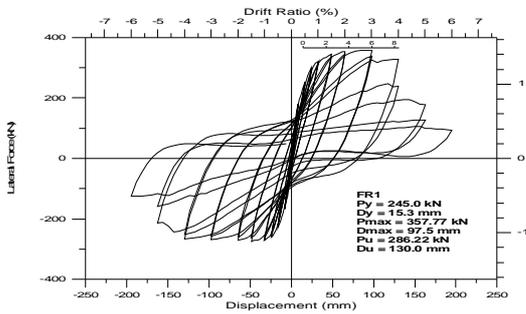


Fig 3. Hysteretic curve of specimen FR1

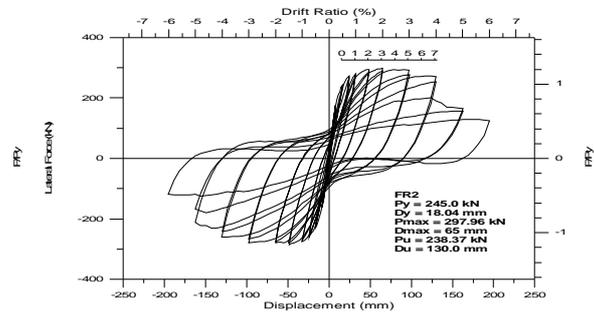


Fig4. Hysteretic curve of specimen FR2

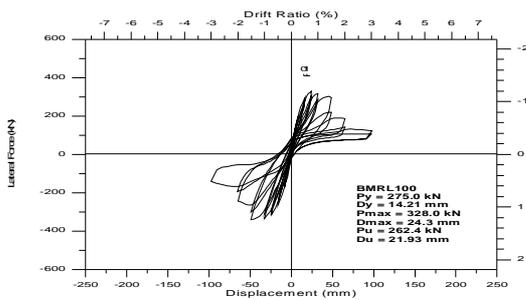


Fig 5. Hysteretic curve of specimen BMRL100

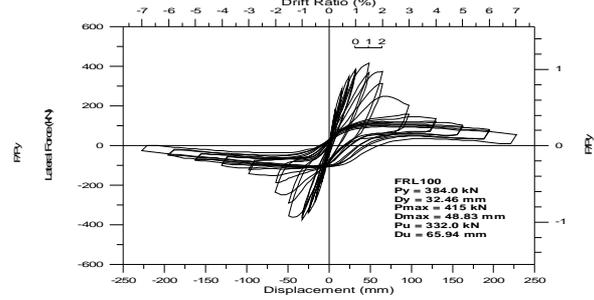


Fig 6. Hysteretic curve of specimen FRL100

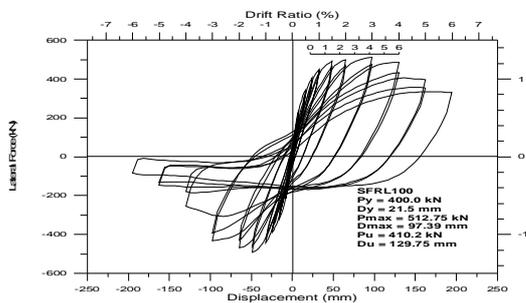


Fig 7. Hysteretic curve of specimen SFRL100

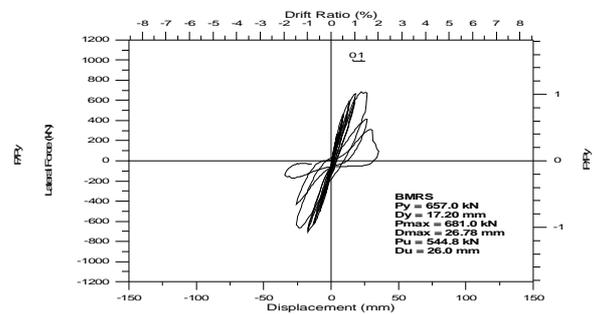


Fig 8. Hysteretic curve of specimen BMRS

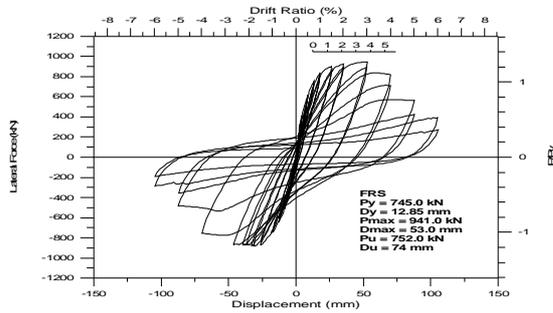


Fig 9. Hysteretic curve of specimen FRS

Table 1 Detail of Benchmark Specimens

Failure Type	Specimen	Cross section (mm)	Height (mm)	Axial Load (f' c Ag)	Material			Longitudinal reinforcement		Transverse reinforcement		Note Code
					Conc. f' c (Mpa)	Long. Rein. f <sub>y</sub> (Mpa)	Trans. Rein. f <sub>yh</sub> (Mpa)	Arrange-ment (mm)	Cut off height (mm)	Arrangement		
										PHZ. (mm)	Non-PHZ. (mm)	
Flexural	BMR1	750*600	3250	0.1	25.97	490	490	32-19Φ	---	9Φ @ 100	9Φ @ 100	New
	BMR2	750*600	3250	0.1	25.97	343	490	32-16Φ	1800	9Φ @ 130	9Φ @ 240	Old
	BMR3	750*600	3250	0.15	25.48	343	490	32-16Φ	1800	9Φ @ 130	9Φ @ 240	Old
	BMR4	750*600	3250	0.15	20.48	386.81	450.8	32-16Φ	1800	9Φ @ 230	9Φ @ 230	Old
	BMR1-R	750*60	3250	0.15	22.05	436.79	450.8	34-19Φ	1800	9Φ @ 100	9Φ @ 100	New
	BMC1	D=760	3250	0.15	25.97	490	490	34-19Φ	---	9Φ @ 70	9Φ @ 100	New
	BMC2	D=760	3250	0.15	25.51	343.35	490.5	30-16Φ	1800	9Φ @ 130	9Φ @ 220	Old
	BMC3	D=760	3250	0.15	21.29	387.2	451.26	30-16Φ	1800	9Φ @ 230	9Φ @ 230	Old
	BMC4	D=760	3250	0.15	20.6	274.68	274.68	30-17Φ	1800	9Φ @ 130	9Φ @ 220	Old
	SC1	D=760	3250	0.15	26	343.35	490.5	26-16Φ	1250	9Φ @ 140	9Φ @ 240	Old
	SC1-R	D=760	3250	0.15	26	343.35	490.5	26-16Φ	1250	9Φ @ 140	9Φ @ 240	Old
FC1	D=750	3250	0.15	26	343.35	490.5	32-16Φ	---	9Φ @ 100	9Φ @ 100	New	
FC4	D=750	3250	0.15	25.51	343.35	490.5	18-16Φ	---	9Φ @ 300	9Φ @ 300	Old	
Shear	BMRS	750*600	1750	0.15	16.67	421.83	412.02	30-19Φ	---	9Φ @ 300	9Φ @ 300	Old
	BMCS	D=760	1750	0.15	16.67	425.22	426.2	30-19Φ	---	9Φ @ 300	9Φ @ 300	Old
Lap - splices	BMRL100	750*600	3250	0.15	16.67	421.83	412.02	30-19Φ	760	9Φ @ 130	9Φ @ 220	Old
	BMRL50	750*600	3250	0.15	17.89	411.6	421.4	30-19Φ	760	9Φ @ 130	9Φ @ 220	Old
	BMCL100	D=760	3250	0.15	19.99	425.22	426.2	30-19Φ	760	9Φ @ 130	9Φ @ 220	Old
	BMCL50	750*600	3250	0.15	20.6	274.68	274.68	30-19Φ	760	9Φ @ 130	9Φ @ 220	Old
Wall type	SW	1250*500 R=250	3250	0.15	16.67	421.83	412.02	8-25Φ	1530	9Φ @ 230	9Φ @ 350	Old
	LW	1250*500 R=250	3250	0.15	16.67	421.83	412.02	8-25Φ	1530	9Φ @ 230	9Φ @ 350	Old
Founda-tion	RF0	245*180	450	0.05	25.2	423.1	423.1	25Φ @ 150	---	25Φ @ 150	25Φ @ 150	New
	RF1	245*180	450	0.05	41.7	423.1	423.1	25Φ @ 150	---	25Φ @ 150	25Φ @ 150	Old
	RF2	245*180	450	0.05	36.8	423.1	423.1	25Φ @ 150	---	25Φ @ 150	25Φ @ 150	Old

Total : 24 benchmark specimens

Table 2 Retrofit & Repair methods of rectangular specimens

Failure Type	Retrofit / Repair Specimen	Benchmark	Note
Flexural	FR1	BMR2	FRP (8 layers)
	FR2	BMR3	FRP (4 layers)
	SR1		Large octagon
	SR2		Ellipse
	SR3		Small octagon
	SR4		Ellipse
Shear	FRS	BMRS	FRP (4 layers)
	SRS1		Small octagon
	SRS2		Ellipse
	BMRS-RC		RC (9cm)
Lap splices	FRL100	BMRL100	FRP (8 layers)
	SFRL100		FRP (layers)
	SRL1		Small octagon
	SRL2		Ellipse
	BMRL100-RC		RC (9cm)
	BMRL50-RC	BMRL50	RC (9cm)
Wall type	FSW	SW	FRP (2 layers)
	FLW	LW	FRP (2 layers)
Foundation	RF3	RF1	RC (10cm)

Total : 19 rectangular retrofit/repair specimens

Table 3 Retrofit & Repair methods of Circular specimens

Failure Type	Retrofit / Repair Specimen	Benchmark	Note
Flexural	SC2	SC1	Steel (3mm)
	SC3	BMC2	Steel (3mm)
	FC2	FC2	FRP (4 layers)
	FC3		FRP (4 layers)
	RCC2	BMC2	RC (9 cm)
	BMCL4-RC	BMC4	RC (9 cm)
Shear	SCS	BMCS	Steel (3mm)
	FCS		FRP (4 layers)
	FCS-1		FRP (3 layers)
	FCS-2		FRP (2 layers)
	FCS-3		High Pressure Epoxy injected
Lap splices	SCL100	BMCL100	Steel (3mm)
	FCL100		FRP (6-2 layers)
	FCL100-1		FRP (4-2 layers)
	FCL100-2		FRP (6-2 layers)
	FCL100-3		FRP (6-2 layers)
	RCCL1		RC (9 cm)
	RCCL2		RC (9 cm)
	BMCL50-RC	BMCL50	RC (9 cm)

Total : 19 circular retrofit/repair specimen