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BEHAVIOUR OF REPAIRED PRETENSIONED PRESTRESSED CONCRETE BEAMS UNDER CYCLIC LOADING

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SUMMARY

The research described herein is an experimental study of the cyclic behaviour of normal and high strength partial prestressed concrete beams. The beams are prestressed using pretensioned system. Eight different specimens consist of four original and four repaired concrete beams were tested by quasi-static cyclic loading. The main variables were the compressive strength of concrete and the ratio between the area of compression and tension reinforcement. The compressive strength of concrete was varied from 30 to 50 MPa's. Beams were reinforced with the same areas of compression and tension steel but different in moment ultimate for positive and negative directions due to the existence of prestressing reinforcement at the bottom side of the section. The results for these beams showed a different cyclic behaviour at each direction of loading. The other beams were designed with similar ultimate moment capacity both for positive and negative directions by using different reinforcement. At the bottom side, the beams were reinforced using ordinary reinforcing bars and pre stressing strand while the top side was reinforced by reinforcing bars only with larger area compared to reinforcing bars in the bottom side. For these beams, the result showed that, the different among the hysteretic curves on positive and negative loading were insignificant. The load and deflection capacities, energy dissipation increase as the compressive strength of concrete increases. The crack patterns were developed by the combination of shear and flexural actions. This leads to a failure resulting from a large compression force under flexural shear compression failure. Re-cast concrete and polymer grouting into damage regions of the specimens carried out repairs. The ultimate loading capacity of the repaired beam was close to the ultimate loading capacity of the original beam until displacement ductility of four. However, the deflection of the repaired beam at displacement ductility of two and four were larger than that of the displacements of the original beams, respectively. Deflection of the repaired beams using polymer grouting was larger than the displacement for the re-cast concrete specimens. However, the failure of the repaired beams using polymer grouting showed a brittle manner as compared to those for the re-cast concrete beams.

INTRODUCTION

Partial Pre stressing Ratio (PPR) is a ratio between ultimate moment contributed by pre stressing reinforcement to the total ultimate moment consisting of pre stressing and ordinary reinforcement. Previous investigations showed that in the range of PPR between forty to seventy percents partial pre stressing concrete beams have capacities to behave in ductile manners. This also applies for the partial pre stressing concrete beams under cyclic loading (Budiono, 1995). Under this investigation four beams were tested and studied. The beams consist of four originals and repaired beams subjected to quasi – static reversed cyclic loading. The original beams were loaded until failure then the specimens were repaired with several techniques and re tested under the same loading condition. The behaviour of original and repaired specimens were observed and studied. The study is mainly in the area of plastic hinges including the study of hysteretic behavior of displacement ductility and energy dissipation. After failure the specimens were repaired and the study was continued to observe the

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behavior. The repair technique used was designed such that depending upon the degree of damage of the specimen. Results showed that the repaired specimens are still able to perform significant behavior for some extent close to the original ones.

TEST SPECIMENS

An experimental test program consisting of four originals and four repaired specimens was undertaken. The beams were partially pre stressed for positive bending, containing both pre stressed and non – pre stressed reinforcement at the bottom of the section and non-pre stressed steel only at the top of the section. The main variables were the strength of the concrete and different ultimate moment between positive and negative moment capacities. Some specimens were sectional designed to have similar moment positive and negative capacities whilst other specimens were designed with different moment capacities. The ultimate moment of the section was determined in accordance with the principals of structural mechanics. This can be achieved by arrangement of the area of non-pre stressed steel both for top and bottom sides of the section. Details of the specimens in terms of dimension and The Partial Pre stressing Ratio (PPR) are given in Table 1, and showed in Figure 1. The pre stressing ratio was calculated for positive moments

Table 1. Specimen Details

Specimen Code	b (mm)	dst (mm)	dsc (mm)	dp (mm)	fc' (MPa)	PPR (%)	Repair Code	Material for Repair
BA 3060 (different ultimate moment)	150	250	50	200	30	60	BAR 3060	re-cast concrete
BM 3060 (equal ultimate moment)	150	250	50	175	30	60	BMR 3060	polymer grouting
BM 4560 (equal ultimate moment)	150	250	50	175	45	60	BMR 4560	polymer grouting
BM 5060 (equal ultimate moment)	150	250	50	175	50	60	BMR 5060	re-cast concrete

MATERIAL PROPERTIES

The mix design of the normal concrete is to comply with the Standard of ACI 211.1-91 for compressive strength of 30 and 45 MPa's and for high strength concrete complying with the ACI Standard 211.4R-93 for concrete strength of 50 MPa.

The strength of concrete is the average strength of concrete cylinders at the time of testing. The results of compression test together with the properties of pre stressed of 7 wire strands and non-pre stressed reinforcement are presented in Table 2. Each specimen was pre-tensioned with an initial force of 50 kN (initial stress of 400 MPa).

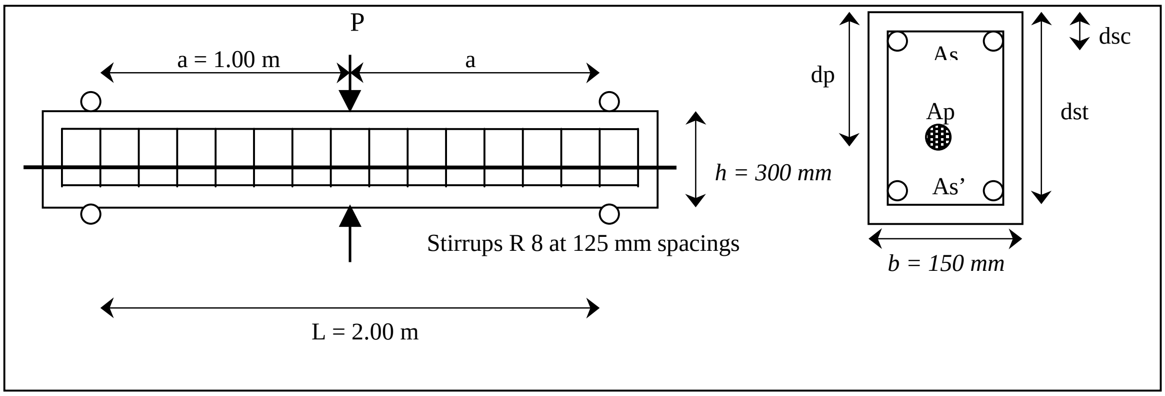

Figure 1 Detail of Beam Specimen

Table 2. Material Properties

Specimen Code	Concrete at Time of Testing		12.5 mm Diameter Strand		Non-Pre stressed Reinforcement		
	Age (days)	fc' (MPa)	fy (MPa)	fpu (MPa)	Y 13 fy (MPa)	Y 10 fy (MPa)	R 8 fy (MPa)
BA 3060	50	36.10	600	1470	-	410	270
BM 3060	28	41.40	600	1470	315	410	270
BM 4560	33	4670	600	1470	315	410	270
BM 5060	33	48.10	600	1470	315	410	270

TEST ARRANGEMENT

The beams were tested with minimum age of 28 days. Simple beams were positioned in the horizontal direction supported by loading frame. The supports of the beams were designed to hold the cyclic reversed loading. The beams were loaded in the middle using reversible actuator. The magnitude of the loads were measured by the load cells with a quasi-static cyclic loading where the load applied in one direction and then reversed. After a predetermined number of cycles at a particular load level, the loads were increased and cycling continued at the increased load interval. A combination of load and displacement controls was used. The magnitudes of loads, displacement, strains were observed using data logger and software running on personal computer.

REPAIR TECHNIQUE

After completion of the test of the original beam, the damage specimen was removed from the loading frame and then repaired. The specimen was still able to repair provided no fractures occurred at pre stressing strand. The technique used in this investigation is conducted as follows :

(i) Pre - pack concrete and polymer grouting :

The damage specimens were straightened held by loading frame. In the plastic hinge region, all of the concrete cover was removed and cleaned from the debris leaving all of the reinforcement and concrete core still remained. A new timber mould was set up in the plastic hinge area and filled with coarse aggregates. Some holes were drilled into the mould and some nipples for grouting were installed. The liquid polymer was grouted into the mould using air pressure through nipples. The polymer used consists of a mixture of polyester resin, styrene monomer, catalyst for hardening, cobalt and fly ash (Suraatmaja, 1998). Along cracks of concrete outside the hinge was taped and some holes was made along the tape to locate the nipples. Through nipples polymer was injected. For injection of the cracks, fly – ash was not used.

(ii) Re – Cast Concrete

After straightening the specimen, the all of the concrete in the hinge zone was removed and cleaned. A new mould was positioned to re – cast fresh concrete with the same concrete mix design. An additive was used to accelerate the concrete strength from 28 days to 7 days. Bonding agent was given at the interface between old and fresh concrete.

INSTRUMENTATION

Instrumentation used in the investigation is as follows:

(i) Actuator, the actuator is a reversible jack to apply the beam cyclic loading. The capacity of the actuator is 120 kN
(ii) Load cell, the load cell is used to measure the magnitude of load produced by the actuator
(iii) Strain gauges are positioned at the longitudinal reinforcement
(iv) LVDT is used to measure the displacement at three different points of locations
(v) Data logger is to read automatically the reading of strain gauges, load cell and LVDT'S.
(vi) Software is to produce plots and graphs on the monitor operated by a personal computer.

LOADING SEQUENCE

Initially, one complete elastic cycle with maximum load of 60% of theoretical ultimate load was applied to each specimen. From the load deflection plot, the maximum elastic deflection at the middle of beam was determined. The displacement at this stage was considered to correspond to a displacement ductility of one. Under the elastic range a load control was applied. Next, two complete cycles into the in elastic range were under taken such that the displacement obtained was twice that corresponding to the ductility of one. This was considered as ductility of two. The loading was then continued to ductility of four etc. Under the inelastic range a displacement control was applied. The complete set of loading sequence is presented in Figure 2.

For repaired specimen similar loading sequence was applied. However, the initial load given was 60 % of the original beams only in the elastic range to prevent any premature failures.

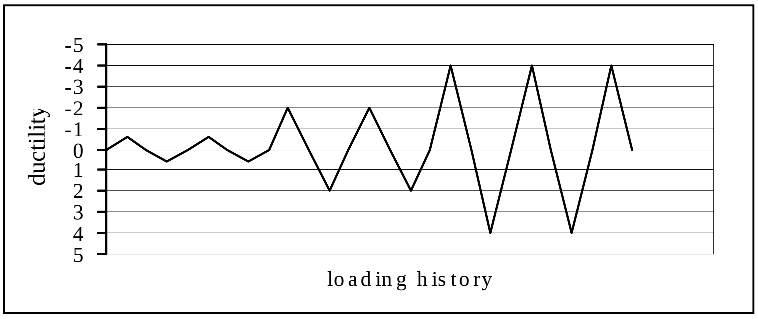

Figure 2. Loading Sequence

TEST RESULTS

All of the specimens developed plastic hinges in the middle of the beams as expected. The observation of the behaviour contains crack patterns, load versus displacements, strength degradation and energy dissipation.

Crack patterns were similar for the entire specimen both for the original and repaired beams. A typical crack pattern is described below. When the load level was applied within in-elastic range a wide crack developed at the plastic region followed by normal cracks distributed along one-third of beam span, in the vicinity of plastic hinge location. In this area, the type of the cracks mostly are flexure – shear cracks. The crack in the plastic hinge region did not close completely when the load was released. However, during the following load reversal, a low load only was required to close the crack. This leads to a pinching effect on the plot of load deflection curve, since a lower portion of the load was carried by the concrete. Once the crack was closed, the specimen gained stiffness as the concrete and the reinforcement resisted the load again. When the load was larger than ductility index of four the specimen failed. The collapse of the specimen occurred when the concrete in the compression area at the top of beam in the hinge zone commenced to crush under the compression action of the concrete and the compression steel to balance high tensile actions developed by pre stressed and non-pre stressed reinforcement (Penta, 1998). Representative test result is illustrated in Figure 3. For the repaired beam, the crack patterns followed the original beam but more severe. Wider cracks were developed. For repaired beams using polymer grouting, horizontal cracks were also developed followed by spalling of the concrete cover at the bottom side of the section. A typical crack patterns for repaired concrete with polymer grouting and crack patterns for repaired re-cast concrete are presented in Figures 4 and 5, respectively.

Figure 3. Crack Patterns of Original Specimens

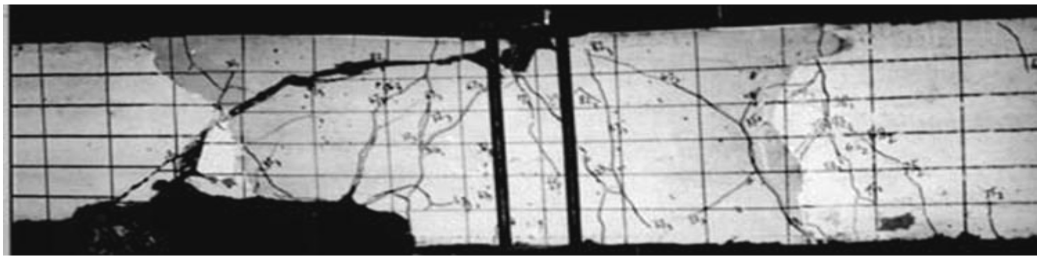

Figure 4. Crack Pattern of Repaired Beam Using Polymer Grouting

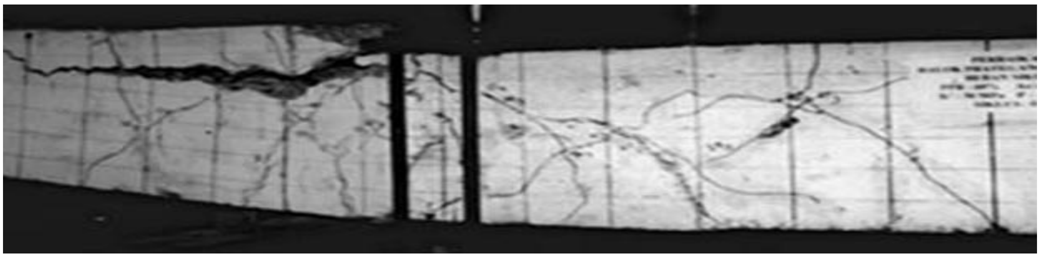

Figure 5. Crack Pattern of Repaired Re – Cast Concrete Specimen

Quantitative values for the hysteretic deflection at several stages of loading is presented in Table 3. Representative test results are illustrated in Figures 6 and 7. Figure 6 represents results of section with different ultimate moment while Figure 7 is to illustrate the hysteretic behaviour of the beams designed with similar ultimate moments of the sections. A significant different of positive and negative ultimate moments as shown in Figure 6 is developed as expected. Figure 7 illustrates that the effect of prestressed strand increasing load capacity of the section designed with similar ultimate moment. However, the increasing load capacity is not quite significant as the load only in ceases close to 20 % of the theoretical ultimate moment.

For the repaired specimens, reduction of load capacities for about 20 % was observed both for polymer grouting and re – cast concrete beams. The reduction of load capacities occurred at the subsequent in elastic loading at the same ductility index as presented in Table 3.

Strength and stiffness degradation were significant for repaired beams. This is because of wide cracks developed at repaired beams could not close again followed by concrete cover spalling and loss of bond stress. The quantitative values of secant modulus and ultimate loads at 5th and 6th cycles both for original and repaired beams are presented in Table 4.

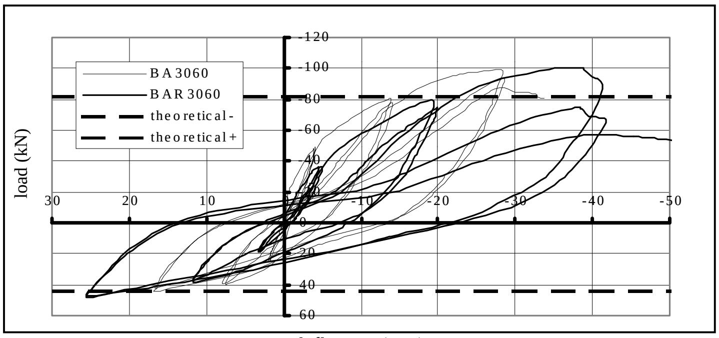

Figure 6. Hysteretic Behaviour of Original and Repaired Beams Designed with Different Ultimate Moment

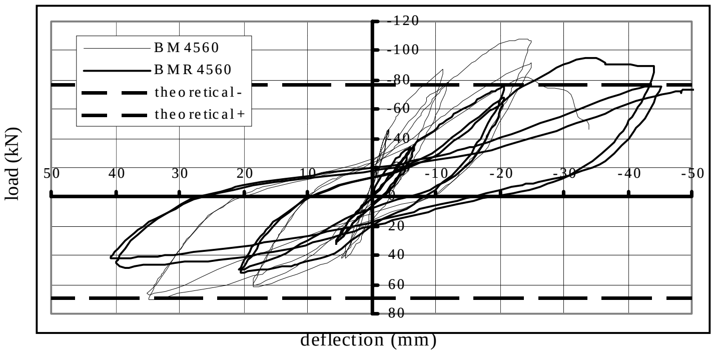

Figure 7. Hysteretic Behaviour of Original and Repaired Beams (BMR4560) with Similar Ultimate Moment

Energy dissipation history shows that as the concrete strength increases the amount of energy dissipation increases. Most of the energy dissipation of repaired beams are greater compared to the original beams despite the pinching effect were more severe in the repaired beams. This is because the repaired beams showing larger deformations as compared to original beams at the same load levels. The history of energy dissipation is illustrated in Figure 8, while the quantitative values are presented in Table 5.

Table 3. Hysteretic Load and Deflections of Original and Repaired Beams

Load and Deflection	Original Beam				Repaired Beam			
	BA3060	BM3060	BM4560	BM5060	BAR3060	BMR3060	BMR4560	BMR5060
Load (kN)								
> Positive Moment :								
- cracking	20.70	26.10	26.00	24.14	20.00	31.03	20.02	22.75
- max elastic	48.80	41.50	45.95	47.61	36.53	31.03	34.54	35.48
- ultimate	99.26	102.48	108.48	112.00	100.38	96.48	94.88	100.02
> Negative Moment :								
- cracking	16.19	16.38	16.47	24.33	14.26	29.39	9.64	18.06
- max elastic	24.23	35.40	42.34	44.08	18.31	26.31	31.74	33.28
- ultimate	44.25	57.48	70.28	62.83	47.88	56.22	48.41	56.01
Deflection (mm)								
> Positive Moment :								
- ductility 2	14.00	11.11	11.91	13.60	19.52	18.42	20.66	12.23
- ductility 4	28.52	23.22	24.79	28.20	41.40	38.30	44.22	26.50
> Negative Moment :								

- ductility 2 - ductility 4	7.90 16.74	12.50 26.62	18.51 34.66	22.65 34.60	11.83 25.42	19.47 38.38	20.55 40.62	18.96 36.27

Table 4. Stiffness and Strength Degradation

Stiffness and Strength Degradation	Original Beam				Repaired Beam			
	BA3060	BM3060	BM4560	BM5060	BAR3060	BMR3060	BMR4560	BMR5060
5th Cycle								
> Positive Moment :								
- Ku (kN/mm)	6.09	4.87	5.41	4.30	4.59	3.48	3.67	100.02
- Pu (kN)	99.26	102.48	108.48	112.00	100.38	96.48	94.88	100.02
> Negative Moment :								
- Kp1 (kN/mm)	1.57	1.91	1.70	1.57	1.06	1.08	.91	1.97
(% Ku)	25.78	39.27	31.37	36.54	23.03	31.14	24.75	35.74
- Pp1 (kN)	16.13	20.25	19.35	21.24	47.88	20.42	5.13	15.44
6th Cycle								
> Positive Moment :								
- Kp1 (kN/mm)	1.53	1.15	1.12	0.97	0.78	1.25	0.61	0.88
(% Ku)	25.16	23.71	20.64	22.67	17.05	35.88	16.60	15.99
- Pp1 (kN)	24.20	30.07	26.56	24.10	22.55		25.09	25.08
- Kp2 (kN/mm)	3.36	3.42	2.78	2.59	2.09		1.70	1.94
(% Ku)	55.18	70.27	51.44	60.29	45.67		46.31	35.21
> Negative Moment :								
- Kp2 (kN/mm)	1.35	1.57	1.50	1.12	1.06	1.07	1.01	1.08
(% Kp1)	85.78	82.22	88.36	71.50	100.00	98.42	111.46	54.91
(% Ku)	22.11	32.29	27.72	26.13	23.03	30.65	27.59	19.63

Table 5. Energy Dissipation (kNmm)

Ductility	BA3060	BAR3060	BM3060	BMR3060	BM4560	BM4560	BM5060	BMR5060
1 (i)	84.13	65.09	52.73	59.69	68.90	95.13	197.70	87.34
1 (ii)	38.31	38.59	33.04	43.59	41.90	81.43	158.16	53.93
2 (i)	651.52	965.42	579.40	1001.63	996.48	1264.36	1337.23	947.96
2 (ii)	415.10	615.20	471.77	821.20	882.21	925.05	1069.78	774.71
4 (i)	1880.85	3122.74	2001.98	3593.58	2688.61	3681.91	3052.28	3018.20
4 (ii)	1395.10	2518.06	1809.20	3521.34	2205.01	3002.26	2441.82	2506.15

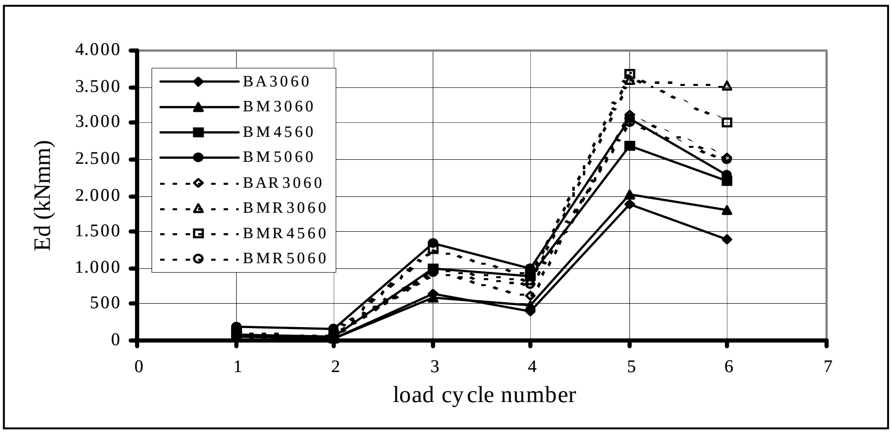

Figure 8. Energy Dissipation History

CONCLUSIONS

1. Crack patterns of the repaired beams follow the patterns of the original beams. Most of the crack developed were flexure – shear cracks. Specimen repaired using polymer grouting collapsed at brittle manner whilst the re – cast concrete failed at a more ductile behaviour.
2. At the same load level larger deflections of repaired beams were observed both for polymer grouting and re – cast concrete specimens. This phenomena increases the amount of energy dissipation of repaired specimens despite the pinching effect was more significant.
3. The amount of energy dissipation increases as concrete strength increases

4. Strength degradation of repaired beams due to cyclic loading was more severe compared to original beams.

REFERENCES

1. ACI Committee 211 : Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete (ACI 211.1-91), ACI Manual of Concrete Practice Part 1, American Concrete Institute, Detroit, 1991
2. ACI Committee 211 : Guide for Selecting Proportions for High Strength Concrete with Portland Cement and Fly Ash (ACI 211.4R-93), ACI Manual of Concrete Practice Part 1, American Concrete Institute, Detroit, 1993
3. Budiono, B. , Gilbert, R.I., Foster, S.J. : Tests on Partially Prestressed Beam – Column Connections under Cyclic Loads, 13th Australasian Conference on The Mechanics of Structures and Materials, University of Wollonggong, July 1993
4. Budiono, B., Munaf, R.D., Liliana : The Behaviour of Repaired Partially Prestressed Concrete Beams Using Polymer and Cement Paste Matrices, 23rd Conference on Our Word in Concrete & Structures, Singapore, August 1998
5. Penta, Titik : Experimental Study on The Behaviour of Partially Prestressed Pretensioned Concrete Beams Under Cyclic Loading, Master Thesis (in Indonesia) Institut Teknologi Bandung, Indonesia, 1998

Suraatmaja, D, et. Al. : The Investigation of Mechanical Properties of Polymer Concrete, Research Report (in Indonesia) Civil Engineering Department, Institut Teknologi Bandung, February 1998