BUILDING FOR THE 21st CENTURY

Proceedings of the Fifth East Asia-Pacific Conference on Structural Engineering and Construction

25 - 27 July 1995

Edited by

YEW-CHAYE LOO

Volume 3

1995

School of Engineering
Faculty of Engineering and Applied Science

GRIFFITH UNIVERSITY
GOLD COAST CAMPUS

EASEC-5

Fifth East Asia-Pacific Conference on
Structural Engineering and Construction

Gold Coast, Queensland, Australia

25 - 27 July 1995

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Printed in Australia by Watson Ferguson & Co, Queensland.

ISBN	Set:	0 86857 671 9
	Volume 1:	0 86857 668 9
	Volume 2:	0 86857 669 7
	Volume 3:	0 86857 670 0

Distributed by School of Engineering, Faculty of Engineering and Applied Science, Griffith University - Gold Coast Campus, Southport, Queensland, Australia, 4215.

BUILDING FOR THE 21st CENTURY, Y.C. LOO (Editor)
 ISBN 0 86857 671 9

STRENGTHENING REINFORCED CONCRETE COLUMNS WITH USE OF POLYMER MORTAR

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ABSTRACT: In this paper, we present a new type of supplementary strengthening method by using polymer mortar and reinforcements to make reinforced concrete piers of bridges effectively resist against earthquake motion. First, in this study we carried out pull-out tests of steel bars and CFRP bars to measure pull-out resistance of the bars placed into polymer mortar. We employed several types of bars having different configurations and lengths of anchor portions. Experimental results confirmed that configuration of anchor portions can be specified based on fundamental data of adhesive strength of material. Second, strengthening reinforced concrete column specimens using polymer mortar and reinforcements, we carried out pseudo-dynamic tests of column specimens. From experimental results, confirmed was the effectiveness of the strengthening using polymer mortar as well as reinforcements.

1. INTRODUCTION

These days, supplementary strengthening of existing structures has been one of important issues in many countries. In Japan, various studies have been conducted to establish strengthening method for existing damaged structures [1]. One of the author has been conducting a study on the effect of repair of reinforced concrete slabs using an under-repairing method with use of polymer mortar and the method was already used for the repair of existing bridges [2]. The purpose of this paper is to investigate applicability of polymer mortar as supplementary strengthening material through some experiments. Also we shall try to use precast CFRP bars as reinforcements in place of steel bars. First we measured adhesive strength of polymer mortar and made sure that this sort of material could be used as strengthening material. Second reinforced concrete column specimens were loaded by means of pseudo-dynamic testing method and confirmed was that combination of polymer mortar and steel bars or CFRP bars is effective to strengthen reinforced concrete column members.

2. PULL-OUT TEST OF REINFORCEMENTS PLACED INTO POLYMER MORTAR

2.1 Testing Apparatus

First we carried out pull-out tests of reinforcements placed into polymer mortar. We used some cubic concrete blocks with sides of 150 mm and some types of anchor holes as shown in Table 1. The reinforcements were anchored into the holes with use of polymer mortar. Fig. 1 shows configurations of anchor portions of the reinforcements. Steel bars of SD30 with diameter of 13 mm and carbon fiber reinforced plastic bars with cross section ranged from 1.55 cm^2 to 1.70 cm^2 were employed as reinforcements. Uni-axial compressive strength of the concrete used was 275 kgf/cm^2 in average. Table 1 also shows types of specimens used in the tests and configurations of the anchor holes opened to place polymer mortar and reinforcements in. Three specimens were used for each type of tests. The age of the concrete was 28 days old and that of the polymer mortar was 7 days old at the moment experiments were carried out. The specimens were set up on a tensile testing machine and the reinforcements were step-wise pull-out monotonically up to failure. Measured were axial strain of the bars and slip displacements of the specimens measured as shown in Fig. 2.

Table 1 Configuration of anchor holes of each specimens

Type	Cross section of anchor hole	Length of anchor hole (mm)
S-type	circle of ϕ 26mm	150
		100
		50
J-type	rectangle of 85mm×18mm	150
		100
		50
L-type	rectangle of 85mm×18mm	150
		100
		50
FS-type	circle of ϕ 26mm	100
		50

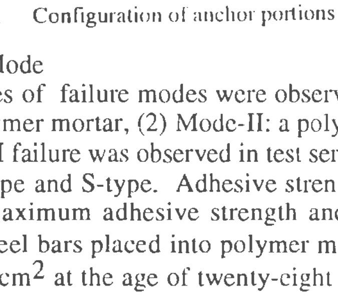


Fig.1 Configuration of anchor portions

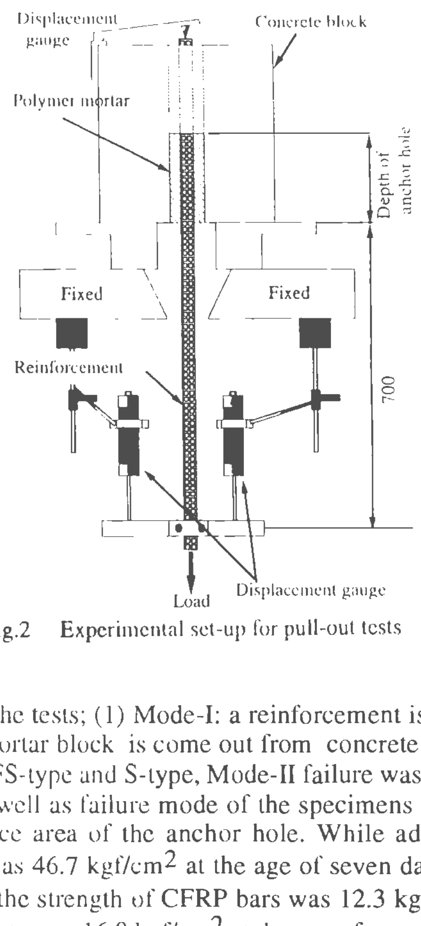


Fig.2 Experimental set-up for pull-out tests

2.2 Failure Mode

Two types of failure modes were observed in the tests; (1) Mode-I: a reinforcement is come out from polymer mortar, (2) Mode-II: a polymer mortar block is come out from concrete block. While Mode-I failure was observed in test series of FS-type and S-type, Mode-II failure was in test series of L-type and S-type. Adhesive strength as well as failure mode of the specimens might depend on maximum adhesive strength and surface area of the anchor hole. While adhesive strength of steel bars placed into polymer mortar was 46.7 kgf/cm^2 at the age of seven days old and 68.6 kgf/cm^2 at the age of twenty-eight days, the strength of CFRP bars was 12.3 kgf/cm^2. Also the strength between polymer mortar and concrete was 16.8 kgf/cm^2 at the age of seven days. While maximum adhesive load of reinforcements in polymer mortar might be the maximum adhesive strength multiplied by the surface area of the reinforcements, the load of polymer mortar might be the corresponding maximum adhesive strength multiplied by the surface area of the anchor hole. Fig. 3 to Fig. 5 show relationships between maximum adhesive load and the lengths of the anchor portions of the specimens in each test series. In these figures, theoretical maximum load value was plotted against the lengths, too. From these figures, we can find that Mode-I failure should have been observed in all over the tests. In all the tests besides some specimens of S-type, Mode-I failures occurred, which consists with the consideration mentioned above. Some specimens of S-type, however, resulted in inconsistent failure modes, mainly because of insignificant difference between maximum adhesive load of polymer mortar from concrete and that of steel bars placed into polymer mortar.

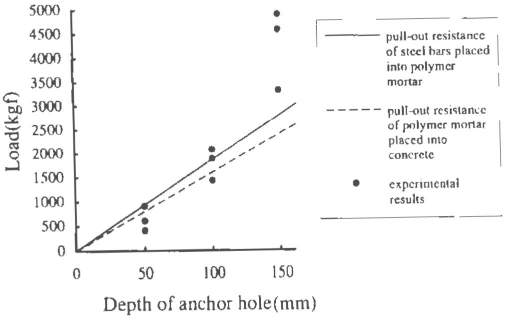


Fig.3 Maximum adhesive load (S-type)

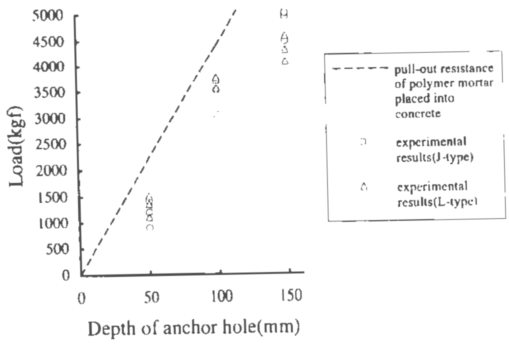


Fig.4 Maximum adhesive load (J and L-type)

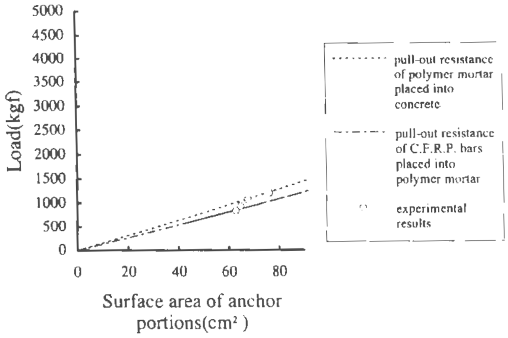


Fig.5 Maximum adhesive load (FS-type)

2.3 Maximum Adhesive Load

Maximum adhesive loads of S-type specimens almost consist with theoretical maximum loads, while those of J-type and L-type with a hook have 80% of theoretical maximum loads mainly because the surface areas of the anchor holes might have been less than those expected in advance. From Fig. 3 and Fig. 4, we can conclude that (1) maximum adhesive load can be evaluated by means of adhesive strength of polymer mortar placed into concrete and the surface areas of the anchor holes, (2) hook shape results in limited influence on maximum adhesive load.

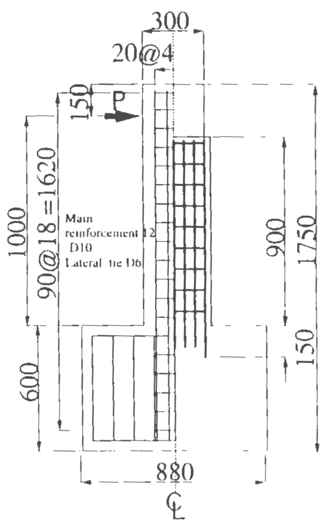
Let us consider that polymer mortar should have sufficient adhesive surface to prevent failure until yielding of steel bars. Using adhesive strength of steel bars placed into polymer mortar (68.6 kgf/cm^2 at the age of twenty-eight days) and the strength of polymer mortar against concrete (16.8 kgf/cm^2 at the age of seven days), we can conclude that in order to anchor a steel bar into polymer mortar we should open (1) a cylindrical hole with diameter of 44 mm and adhesive length of 140 mm or more as S-type anchor is used or (2) a rectangular hole with 200 cm^2 as J-type or L-type anchor is used.

In case that CFRP bars are used as reinforcements, maximum adhesive load was about the same as the theoretical maximum load or more and was in proportion to adhesive surface area. In order to effectively use the CFRP bar's characteristic of relatively high tensile strength , a set of lib should be arranged on the surface of the bars.

3. LOADING TESTS FOR REINFORCED CONCRETE COLUMN SPECIMENS

3.1 Unstrengthened Specimens

Two small-size unstrengthened reinforced concrete specimens simulating cantilever piers of bridges were used for the test. Both of cantilever piers were framed in a massive reinforced concrete footing anchored to a test floor by means of post tensioned rods. Both of the unstrengthened specimens have the same characteristics over the cross section of 30 cm * 30 cm, height of 100 cm, main reinforcement ratio of 0.95% with use of 12 SD30 bars (deformed bars) with diameter of 10 mm, and tie reinforcement ratio of 0.235% with use of SD30 bars (deformed bars) with diameter of 6 mm, as shown in Fig. 6 and Table 2. Uni-axial compressive strength of portland cement was 255 kgf/cm^2 in average, and the maximum grain size of aggregates was set to 20 mm.



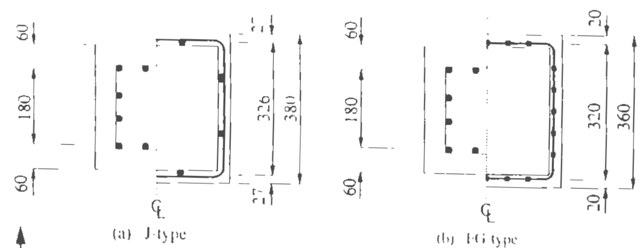


Fig.6 Configuration of RC-column specimens

Table 2 Types of strengthening and steel ratio of specimens

Spec	Reinforce-ment	Type	Depth of anchor holes (mm)		Cross section of anchor holes	Axial steel ratio(%)		Lateral tie ratio(%)	
						*1	*2	*1	*2
No 1	D13	J-type	150	100	rectangle of 85mm×26mm	0.95	2.08	0.235	0.469
No.2	C.F.R.P.	FG-type	150	100	rectangle of 250mm×26mm	0.95	1.90	0.235	0.473

*1: before supplementary strengthening
*2: after supplementary strengthening

3.2 Strengthening of the Specimens

Supplementary reinforcements were placed around the specimens and anchored into the footings by means of polymer mortar. Configurations of the anchor holes are shown in Table 2. For the J-type specimen, 8 SD30 bars with diameter of 13 mm were placed, and main reinforcement ratio increased to about 2% after supplementary strengthening. For the FG-type specimen, used were precast CFRP members with 20 main CFRP bars (including carbon fiber of 40%) with cross sectional area of 0.59 cm^2. Each specimen has different types of anchor portions as shown in Fig. 7.

After some anchor holes with configurations as shown in Table 2 were opened by means of a drill, all the reinforcing members were placed around the specimens and into the anchor holes, and some polymer mortar was filled into the holes. After that, polymer mortar was placed around the specimens. Tests were carried out at the moment the age of polymer mortar was twenty-eight days and the age of concrete was twenty-eight days or more. Anchor holes with depth of 150 mm were opened at two sides that would be subjected to maximum tension and compression stress, while the holes with depth of 100 mm at the other two sides because it was impossible to open any deeper hole due to steel bars placed into the footings of the specimens.

3.3 Loading Condition

Modeling the specimens as a single degree of freedom system with initial eigen period of 0.4 sec and damping coefficient of 0.05, pseudo-dynamic testing technique was used to apply cyclic loads to the specimens. NS component of Acceleration record observed at Elcentro Earthquake was used as input acceleration. Maximum acceleration value of the input wave was increased by 10 gal with increasing number of loading, and each specimen was tested twice with the same absolute value of the maximum acceleration in the reversed direction of loading to prevent accumulation of plastic deformation in one direction. Simulating weight of superstructures, 6% (9.3 tf) of design load capacity in axial-direction was loaded to the specimens as a constant axial force. The specimens were loaded at the cantilever tip by means of an electtro-hydraulic actuator with maximum load value of 30 tf as shown in Fig. 8.

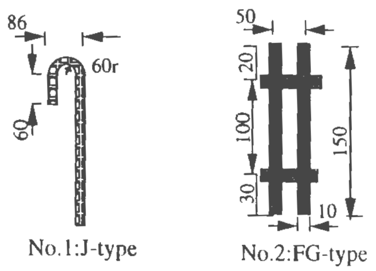


Fig.7 Configuration of anchor portions of reinforcements

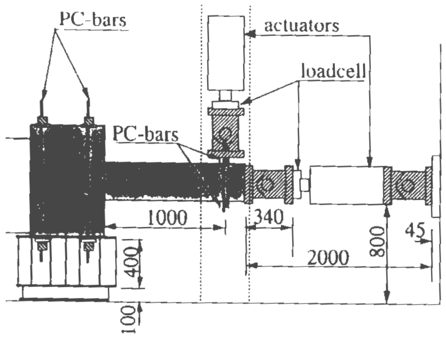
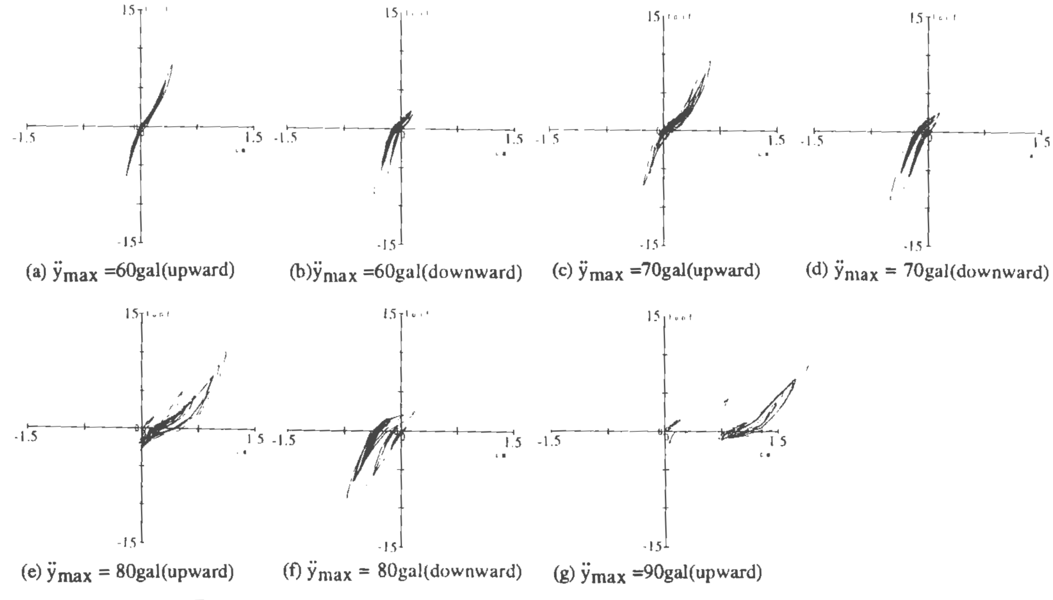


Fig.8 Loading setup for pseudo dynamic tests

3.4 Hysteresis Behavior

Fig. 9 and Fig. 10 shows reaction force - displacement relationships of the specimens, respectively. Fig. 11 was also drawed by plotting maximum reaction force against maximum displacement amplitude for all the loading step in each test.

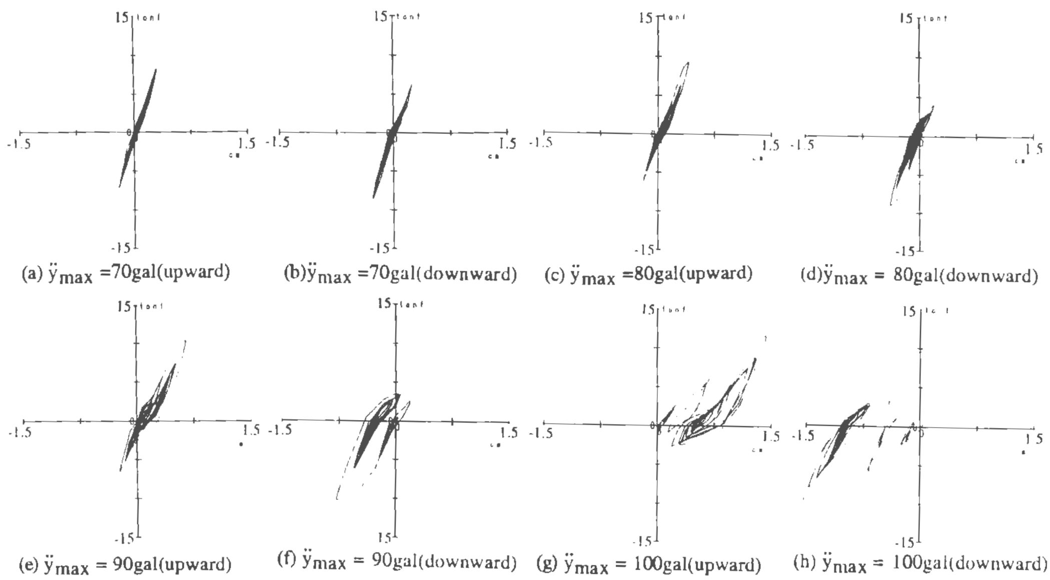
Although both of specimens were loaded until the displacement at the loaded point exceeded the capacity of the displacement gauge of 50 mm, the specimens did not fail despite the specimens resulted in some relatively wide cracks. Load-displacement relationships for both of the specimens were similar and confirmed was that both of supplementary strengthening methods were effective. Comparing the load capacity of the specimens with those of the same kind of specimens having anchor holes with depth of 80 mm reported by the authors [3], the present specimens were much stronger than those in the reference by 30% or more.



(a) $\ddot{y}_{max}$ =60gal(upward) (b)$\ddot{y}_{max}$ =60gal(downward) (c) $\ddot{y}_{max}$ =70gal(upward) (d) $\ddot{y}_{max}$ = 70gal(downward)

(e) $\ddot{y}_{max}$ = 80gal(upward) (f) $\ddot{y}_{max}$ = 80gal(downward) (g) $\ddot{y}_{max}$ =90gal(upward)

Fig.9 Reaction force - displacement relationships (J-type)



$\ddot{y}_{max}$: maximum value of input acceleration

Fig.10 Reaction force - displacement relation (FG-type)

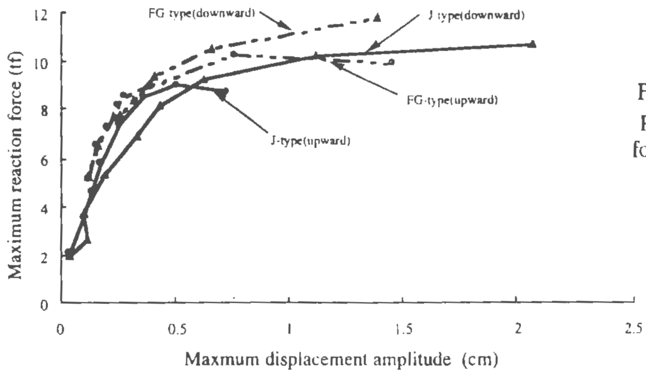


Fig.11
Relationships between maximum reaction force and maximum displacement amplitude

4. CONCLUSIONS

Conclusions obtained in this study are as follows.

(1) Polymer mortar is applicable as anchor material placed around reinforced concrete cantilever columns to supplementary strengthen the columns.

(2) CFRP bars as well as steel bars can be used as supplementary reinforcements.

(3) It is possible to specify the configuration of anchor portion based on the fundamental data on adhesive strength of between two of concrete, polymer mortar and reinforcements.

5. REFERENCES

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