AN INVESTIGATION OF MECHANICAL RELIABILITY OF SHEAR WALL REPAIRED WITH EPOXY MORTAR

by

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SYNOPSIS

Structural walls of reinforced concrete buildings subjected to severe earthquake or differential settlement sustain the inclined and "X" patterned shear crack damage due to large shear deformation. In the case that bars of reinfocement are not yet broken and the boundary frame is still stiff, these shear walls will be able to be repaired. Therefore, one should clarify the effectiveness of the restoration of the repaired wall. This paper investigates experimentally the mechanical properties of repaired shear walls.

INTRODUCTION

Repairs of structural concrete elements following damage induced by earthquakes or diffrerntial settlements are not uncommon. Especially in earthquake zones such repair is frequently necessary. We have only a few papers which investigate mechanical properties of repaired members, although there are some papers about the experimental studies on repaired reinforced concrete columns(1) and beam column joints(2)etc., and the reports on actually performed repairs of concrete buildings damaged by San Fernando Earthquake of Feb.9, 1971(3,4). Such data are valuable in assessing service capabilities of repaired member and degree of restoration of buildings after repair.

This paper investigates experimentally the load carrying capacities, deflection properties, capabilities for energy absorptions and failure properties of shear walls damaged by the diagonal cracks previously and repaired with epoxy mortar which is the most suitable among the various materials available for the repair of concrete. By comparing with each other the various properties before and after repair, the effect of restoration of shear walls shall be clarified.

TEST PROGRAM

The actural shear walls have various values of height to horizontal length ratio, thickness, amount of reinforcement and dimensions of surrounding frame etc., but in this present test program, size and shape of the specimens were limited to such as square shape(100×100cm) with thickness of 4cm inside the boundaty frame with square cross section(20×20cm) as shown in Fig.1. The amount of reinforcement was taken to be of the following three kinds, plain concrete termed CW, small amount of reinforcement, RCW-A, and large amount of reinforcement, RCW-B.

The first set (termed CASE-I) of each specimen of CW, RCW-A and RCW-B were subjected to continuous cyclic loading to their maximum loading capacities without repair, and they represent the original properties. According to such experimental result that cracks occur generally at the shear deformation of $R=2\times10^{-4}\sim4\times10^{-4}$ and the yielding values of shear deformation are approximately limited to $2\times10^{-3}\sim3\times10^{-3}$, the second set (CASE II) and the third set (CASE III) of specimens were, at first, loaded aimed at $R=1.5\times10^{-3}$ and 3×10^{-3}, respectively. The former simulates the medium damage and the latter the severe one. Next, unloading to zero load, the crack damage was repaired and the specimens were loaded again to failure.

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TEST SPECIMEN AND MATERIALS

Cross sectional area of the boundary frame($400cm^2$)is the same as that of the inside wall. It was designed so as to restrain deformation of the inside wall, so that almost uniform shear stress distribution can be obtained before initial crack of the inside wall, and the specimen has more load carrying capacity as well as ductile shear deformation after initial crack.

The reinforced concrete walls have the equal amount of vertical and horizontal reinforcement. RCW-A and RCW-B have 0.195% and 0.389% reinforcement of its cross sectional area of the inside wall, respectively, which are less and more than the minimum amount of 0.25% provided by the regulation of the Architectural Institute of Japan(5). The test specimens were CW-I,II, RCW-A-I,II,III, RCW-B-I,II,III, and one frame without inside wall, consequently amounted to nine.

Mixing proportion by weight for the concrete was 1:3.3:3.1:0.75 for Portland cement, sand (0.3mm∿2.5mm), gravel (2.5mm∿15mm) and water, respectively. The concrete had a slump of about 22.7cm. Mixing proportion by volume for the epoxy compound was 2:1 for two parts of epoxy resin and hardener. Epoxy mortar was mixed by the proportion of 1.0:0.5:3.5 by weight for epoxy compound, tailing of asbestos and selica sand. The reference data of the compressive strength and the modulus of elasticity for epoxy compound are $870kg/cm^2$ and $99,000kg/cm^2$, and compressive and tensile strength for epoxy mortar are $680kg/cm^2$ and $190kg/cm^2$, respectively. The mechanical properties of reinforcing bars and conctete are shown in Table 5.

METHOD OF LOADING AND MEASUREMENT

As shown in Fig.1, reinforced concrete walls were subjected to alternately increasing load between I and I and between II and II points, such as $0 \to 5 \to 0 \to -5 \to 0 \to 10 \cdots$ in ton, and plain concrete walls were loaded repeatedly only in one direction such as $0 \to 5 \to 0 \to 10 \to \cdots$ in ton. Deformation of the frame was measured at eight positions between I and II points. Strain in vertical and horizontal bars at the central part of the wall was measured at two points, respectively. Strain on the concrete surface before repair was measured at nine points in the quarter part of the inside wall.

PROCEDURE OF REPAIR

Most of the cracks had narrow width of less than 1mm, so repair of the walls was led to adopting such method as follows:

(1) The cracks are V grooved to the depth varying approximately from 1cm to 1.5cm and the width of about 3cm by the use of light chipping hammer.

(2) After removing the loose concrete and cleaning the repaired zone, epoxy compound is applied to the surface of the groove.

(3) Epoxy mortar is packed into place closely and the specimens are cured in air under the laboratory conditions for a week until testing after repair.

EXPERIMENTAL RESULTS

As an example, RCW-B-II at test termination is shown in Photo.1, where the pattern of the cracks of before and after repair can be seen. During the loading before repair, for CW-II and RCW-A-II, only two diagonal cracks appeared and widened gradually as the load increased. As a matter of course, the wall with more reinfocement which sustained larger shear deformation has more number of wide spread cracks, and RCW-B-III had the maximum number of seven visible cracks before repair. During the loading after repair, at the loading level lower than that of initial crack in the test before repair, short cracks appeared in some specimens which seemed to already exist before repair but not be repaired. New long cracks across the wall occurred uncontinuously at the repaired zones. Near the maximum loading stage, new short cracks occurred on both sides of the repaired zone where the large stress is distributed. The concrete band adhered with epoxy mortar separated from the wall partially along the diagonal line. In the case of the repaired specimens, at the maximum loading stage, though the widened crack of the wall along the diagonal line is not so obvious as the original one, it induced formation and development of the plastic hinges at the corner zones of the frames, and spallings occurred partially in the inside wall.

Before repair, the strain in the reinfocing bars in the widely cracked zones must exceed the propotional limit strain of 2.35×10^{-3}, though the average normal strain of the wall denoted by R/2 is less than the value of the propotional strain. Except for the case RCW-A-II, the strain in the bars of the walls before and after repair were almost the same and naught until the load level of initial crack. The strain in the bars of CASE RCW-A-II is shown in Fig.3 as an example. In this case after repair, considerably large tensile strain developed in the bar even for low loading level. This may be because unrepaired cracks existed.

As shown in Fig.2 the characteristics of inverse S shape in the unloading stage were emphasized as the number of cyclic loading increased at high load level. Bars in the cracked zones may have imperfection caused by loss of bond, and the concrete had significant micro cracks. In addition, similar adverse effects may have been introduced by the operation of repair. Since epoxy mortar used for repair has relatively lower modulus of elasticity in spite of its high strength, such stiffness as in the original wall could not be recovered even in the repaired zones which were V grooved and packed by the epoxy mortar.

The properties of the repaired wall can be no more the same as those of the original one. The results are shown in Table 1, in which the "prime" mark (') represents "after repair".

Typical characteristics of the repaired wall are summerized as below:

(1) Stiffness. In the case of reinforced concrete wall specimens, since stiffness obtained in this test is a little different under the loading in two directions, it is presented as the equivalent stiffness as shown in Fig. 5. The results are shown in Fig.3. The ratio of stiffness after repair to that before repair are represented in Table 2. After all, stiffness change by the repair is summerized as follows:

(i) The repaired walls exhibit relatively large deformation increase at low load level compared with the wall before repair and the initial stiffness of repaired wall was about 90% and 50% of that before repair for RCW-A and RCW-B, respectively. The more remarkable reduction of initial stiffness for RCW-B with more reinforcement must be introduced by the disadvantageous condition with more numbers of repairs of visible cracks, more widely spread micro cracks and loss of bond.

(ii) At the maximum load before repair, the stiffness of repaired walls showed a little increase except for RCW-A-II with about 8% reduction. Over this loading stage, the stiffness before and after repair were almost same.

(iii) By comparing stiffness at low loading level in the first cycle after repair with that in the last cycle before repair, it is found that the remarkable restoration was obtained.

(2) Equivalent Viscous Damping. The equivalent viscous damping factor, h, was estimated as an approximate value on a hysteresis loop by such method as shown in Fig.5. A little different values in two directions of loading were averaged. The values of h of repaired wall for some levels of deformation and recovery ratio using these averages are shown in Table 4. Among the cases of RCW-A-II, III and RCW-B-II, the value of h were about 8.4% ~ 9.6% and the damping after repair appeared to reserve the value before repair. But in CASE RCW-B-III which had many numbers of repaired cracks of all the

specimens, the value of h was about 6.6%∿7.8% and was 33% less than the value before repair.

(3) Strength and Ductility. For CW-II, RCW-A-II,III, RCW-B-II and III,the sustained maximum load levels before repair were 64, 77, 96, 67 and 73% of the ultimate shear atrength of each original specimen, respectively, and naturally confirmed original strength as shown in Table 4. With respect to CW-II, the load level at initial crack is considerably larger than the other walls. It seems that the thickness of the wall was about 6% larger than the nominal one and only one crack occurred apart the diagonal line of the wall. Additionally, the allowable service load permitted for these walls by the regulation of A.I.J. were obtained as 6.9, 9.3 and 11.6 tons for CW, RCW-A and RCW-B, respectively.(Allowable tensile strength for bar is taken as 3.0t /cm^2) The ductility, Table 4, possessed the same with the original one.

CONCLUSIONS

In the case that the reinforcing bars are not yet broken and the boundary frame is still stiff, the crack damaged shear wall system will be able to be repaired. These walls in the real structure subjected to dynamic severe load should be studied. In this test, results obtained from a limited series of five shear walls repaired with epoxy mortar have been presented and compared with corresponding test results of the original wall or that before repair. The following results were obtained:

(1) These repairs provided walls with the adequate strength and as to the ultimate strength the repaired walls possessed nearly 100% of that of the original ones.

(2) The repaired walls showed a remarkable drop in the initial stiffness. But regarding the rigidity in the extensive range of subsequent large deformation, there was no significant difference between the repaired and original ones.

(3) The repaired walls had sufficient ductility that is good capability of deformation until the ultimate strength, and the brittle failure did not occur.

(4) At the range of the large shear deformation ($>1.0\times10^{-3}$), both the repaired and the original walls showed good coincidence in the capability of energy absorption. The equivalent viscous damping factor for these walls was obtained as nearly 9%.

(5) The repaired wall with larger amount of reinforcement shows comparatively larger reduction in initial stiffness and in damping factor, though this tendency is related to imperfection of repair.

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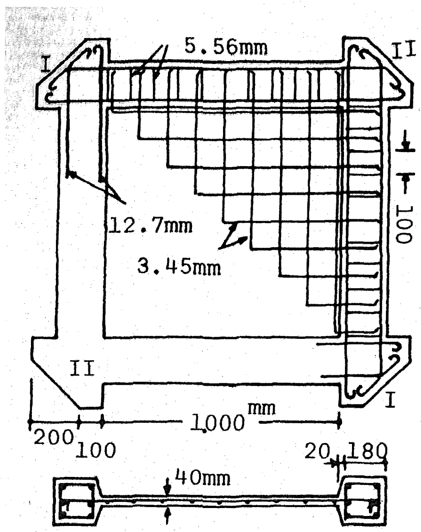


Fig. 1 Specimen
(in CASE RCW-A)

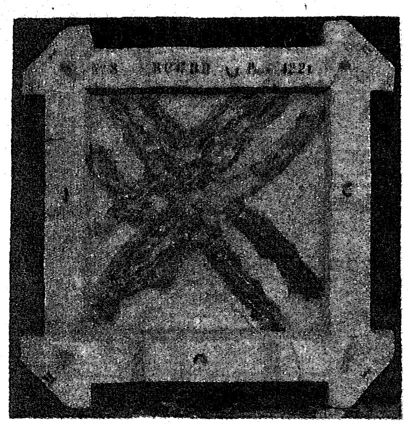
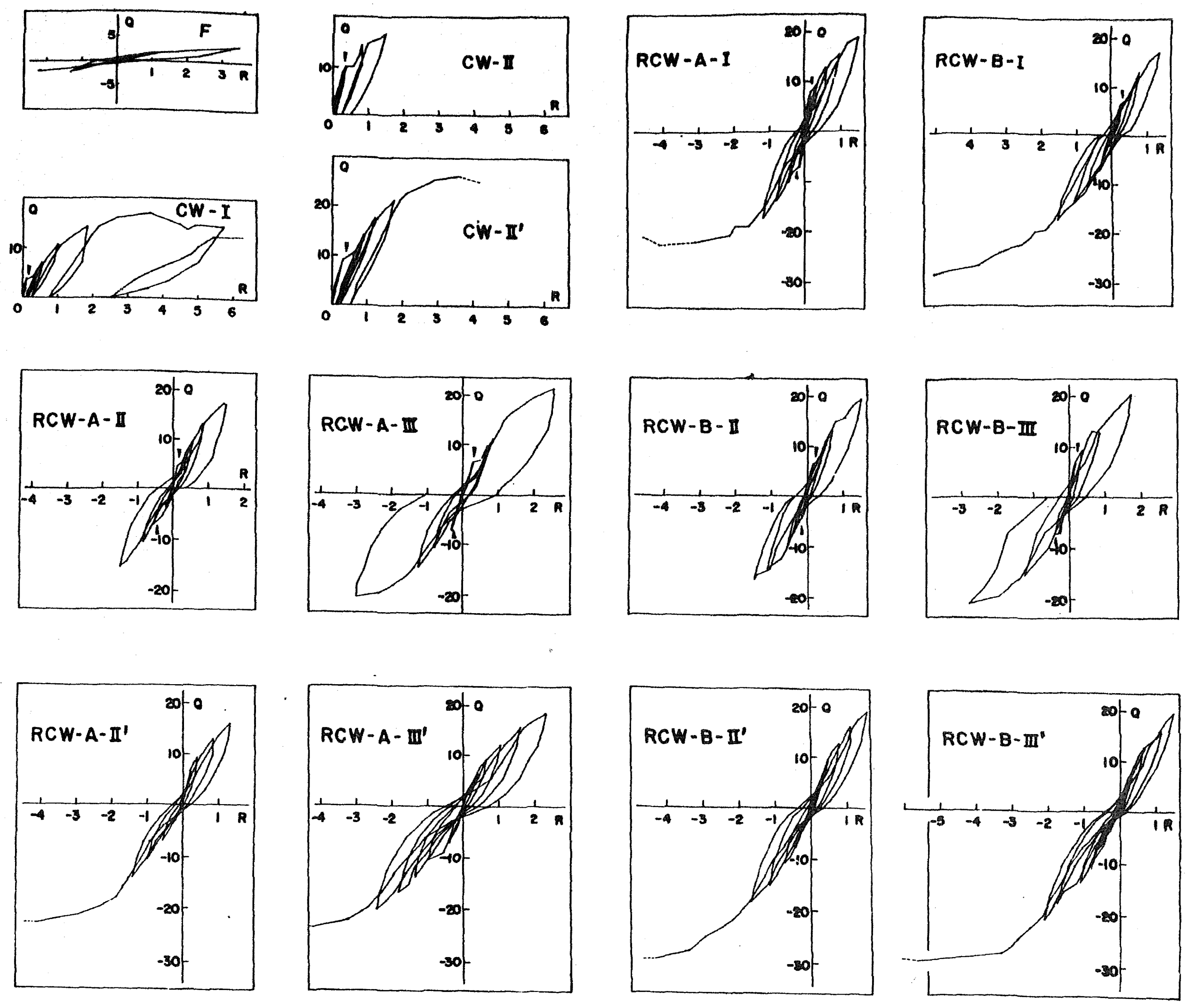


Photo.1 Specimen after Test
(in CASE RCW-B-II)



(Q:in ton, R:in 10^{-3}, ('):Initial Crack)

Fig. 2 Shear Force Q vs. Deformation R

Table.1 Test Results

Specimen	(Q/R)i 10^3ton /rad.	Qcrack ton	Rcrack 10^{-3}	Qrange ton	Rrange 10^{-3}	Rres. 10^{-3}	Qulti. ton	Rulti. 10^{-3}
Frame	1.2	—	—	—	—	—	5.0	—
CW-I	3.2	5.23	0.17	—	—	--	17.0	3.6
CW-II	48.1	10.20	0.34	0.0~16.7	0.0 ~1.48	0.49	—	—
CW-II	32.8	10.60	0.40	—	—	—	26.2	3.6
RCW-A-I	51.6	8.83	0.22	—	—	—	-22.6	-4.1
RCW-A-II	32.8	6.89	0.30	-15.5~17.3	-1.50~1.42	0.35	—	—
RCW-A-II	32.1	—	—	—	—	—	-22.8	-4.1
RCW-A-III	23.2	6.72	0.29	-20.5~21.6	-3.00~2.55	-1.04	—	—
RCW-A-III	21.8	—	—	—	—	—	-23.2	-4.2
RCW-B-I	20.4	8.56	0.40	—	—	—	-28.8	-5.1
RCW-B-II	41.3	7.00	0.21	-16.5~19.4	-1.49~1.50	-0.34	—	—
RCW-B-II	19.8	—	—	—	—	--	-29.8	-5.7
RCW-B-III	34.0	9.09	0.33	-20.9~20.3	-2.83~1.72	-0.61	—	—
RCW-B-III	17.4	—	—	—	—	—	-29.2	-5.6

Note; Specimens with prime mark are repaired one.
(Q/R)i: Stiffness at the lowest experimental load level.
Qrange: Loading range before repair.
Rrange: Shear deformation range before repair.
Qulti: Ultimate shear strength. Rulti: Ultimate shear deformation.
Rres: Residual Shear deformation before repair.

Table 3 Variation of Damping

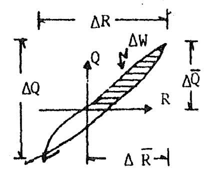
	$\Delta\bar{R}(10^{-3})$	A-II	A-III	B-II	B-III
h(%)	1.0	8.6	9.6	8.6	6.6
	1.5	8.6	8.8	8.4	7.6
	2.0	—	8.6	—	6.7
h'/h		1.01	0.99	0.88	0.67

h'/h: Ratio of h of repaired to that before repair.

Table 4 Variation of Ultimate Q and R

	CW II	RCW A-II	RCW A-III	RCW B-II	RCW B-III
Qulti. / Qo,ulti.	1.54	1.01	1.03	1.03	1.01
Rulti. / Ro,ulti.	1.00	1.00	1.00	1.12	1.10

Qo,ulti.: Ultimate shear strength in CASE I. Ro,ulti.Ultimate shear deformation in CASE I.



$h=\dfrac{\Delta W}{\pi \Delta\bar{Q}\cdot\Delta\bar{R}}$

$\dfrac{\Delta Q}{\Delta R}$:Equivalent stiffness.

Fig. Equivalent Stiffness and damping

Table.2 Variation of stiffness

	CW II	RCW A-II	RCW A-III	RCW B-II	RCW B-III
Gi'/Gi	0.68	0.95	0.94	0.51	0.54
Gm'/Gm	1.05	0.92	1.02	1.02	1.18
Gi'/Gmi	3.23	5.66	5.44	3.36	2.78

G=Q/R. Gi: inittial stiffness.
Gm: Stiffness at the maximum load level before repair.
Gmi: Stiffness at the lowest loading stage in last cycle before repair.

Table 5 Properties of Materials

	d	E	σe	εe	fu
Wall bar	3.45	2.01	4.7	2.35	6.0
Frame bar	12.7	2.02	3.15	1.55	3.8
Stirrup	5.56	2.08	5.5	2.70	6.7

d(mm):Diameter. fu(ton/cm^2):Strength.
σe(ton/cm^2):Stress at elastic limit.
εe(10^{-3}) :Strain at elastic limit.

Concrete:
Compressive Strength σc=147kg/cm^2
Tensile Strength σt=13.1kg/cm^2
Original Modurus Eo=1.93×10^{5}kg/cm^2
Poisson's Ratio ν=1/6

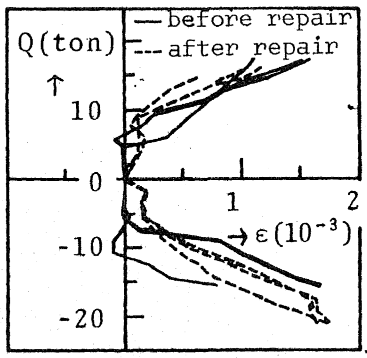


Fig.3 Stress of Bars (in CASE RCW-A-II)

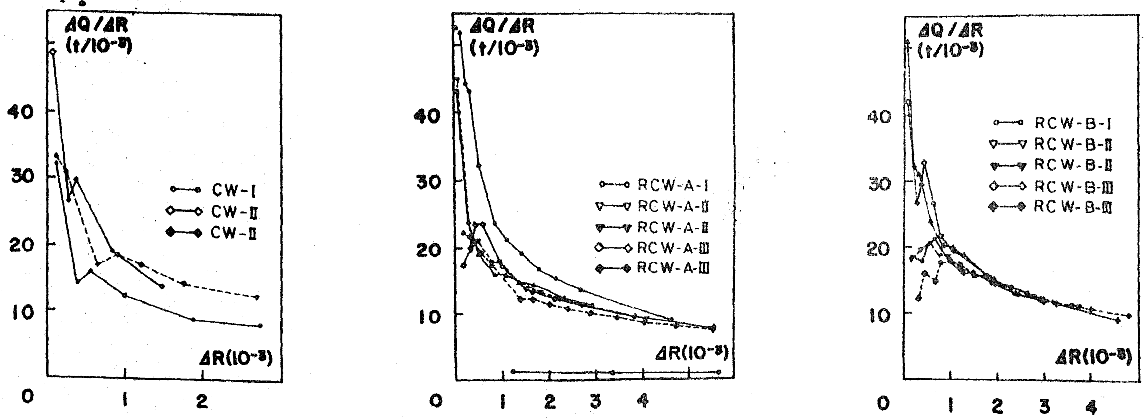


Fig. 4 Stiffness vs. Deformation