U.S.-JAPAN COOPERATIVE RESEARCH ON R/C FULL-SCALE BUILDING TEST

PART 3 INSTALLATION ON NONSTRUCTURAL ELEMENTS AND REPAIR WORKS, DAMAGE ASPECTS AND HYSTERESIS PROPERTIES AFTER REPAIR

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SUMMARY

This report presents general test results of full scale seven story reinforced concrete building after repair works and installation of nonstructural elements. Through the pseudo-dynamic tests and vibration tests, following items were discussed; repair effect by epoxy injecting, recovery of stiffness, strength, natural period of the structure, relationship between damage aspects of nonstructural elements and relating story drift angle.

1. INTRODUCTION

A series of pseudo dynamic tests made much structural damage to the full scale seven story structure. Then the repair works and the installation of nonstructural elements were done in order to inspect the effect of repair works and the relationship between the structural damage grade and the obstacles of nonstructural elements. Because of the installation of the nonstructural elements, it was impossible to discuss clearly the effect of repair works. However the damage progress after repair was possible to be compaired with those before repair under the same sequence of earthquake input. At the same time the actural behaviour of nonstructural elements in the full scale building was able to be observed in the measured story drift.

2. REPAIR OF DAMAGE

After a series of tests on the bare frame, wide cracks were observed at the beam ends, especially in those beams framing into the wall, and in the first three stories of the wall. Epoxy resin was injected into the cracks in the wall and at the ends of beams as shown in Fig.2.1.

Spalled concrete at the ends of beams framing into the wall was replaced by epoxy mortar. Buckled longitudinal reinforcing bars were cut and replaced by parallel bars welded at the cut point. Additional U-shaped stirrups were provided for the slightly bucked bars. Typical repair works at beam ends are shown in Fig. 2.2.

In parallel with the repair work, reinforced concrete spandrel walls were set at one span of the A and C fremes from the second floor to the top floor level as shown in Fig. 2.3. On the second and the third floors,

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(I) Building Research Institute, Ministry of Construction, Japan the reinforcing bars of the spandrel walls were anchored to the columns and floor slab by inserting anchor bolts. At other stories, those anchors had been set in advance. As shown in the lower left hand side in Fig.2.3, the connection of the spandrel wall with the column in frame-C is different from that used in frame-A which had a narrow thickness (6cm).

3. INSTALLATION OF NONSTRUCTURAL ELEMENTS

When the repair works were completed, nonstructural elements were placed in the test structure. The layout of the partitions is shown in Fig.3.1 and Table 3.1. The ceiling was also installed in a part of the third story.

Partition-GBM-1 was set from slab to ceiling and partition-GBM-2 was set from slab to slab. Since there was no ceiling on the fifth story, all partitions were set from slab to slab. Ordinary steel flush doors were built in the center of all partition walls (except for ALC walls).

The notations A and B indicate the boundary conditions between the partitions and the columns. In the case of A, there was clearance of 30mm between a partition and a column. This clearance was intended to give accommodation to the movement of the partitions. In the case of B, there was no clearance.

Aluminum sashes were built on the reinforced concrete spandrel walls (Table 3.1). No.2 and No.5 were sliding windows and the others were fixed ones. No.1,2 and 3 were glazed with elastic sealant and No.4.5 and 6 were glazed with the substitite of hardening putty (mixture of epoxy resin and carbonate of lime).

Glasses of AL-1 and 3 were reinforced with vinyl adhesive tapes (50 mm wide) with spacing of 100 mm on center in order to prevent the fragments of broken glasses from falling. Glasses of AL-2 were reinforced with polyester adhesive films which were specially intended to prevent the fragments of broken glasses from scattering. Glasses of AL-4 were wired glasses.

4. GENERAL BEHAVIOR OF STRUCTURE AFTER REPAIR

4.1 GENEAL BEHAVIOR

The sequence of pseudo dynamic tests for the full scale test building after repair was planned to be quite the same as the one used before repair. Four earthquake motions were planned to be used in the tests, modified 1978 Miyagi-Ken Oki earthquake N-S direction of maximum 23.5 gal (SPD-5) and 105.0 gal (SPD-6); modified 1952 Taft E-W direction of max. 320 gal (SPD-7); and 1968 Hachinohe E-W direction of max. 350 gal (SPD-8). However, in the actual test series, SPD-8 was changed to be a static loading test (SL-3) with uniform load distribution because of the limitation of the actuator capacity. The test results are summarized in Table 4.1. In SPD-5 and SPD-6, the response displacements were larger than those before repair. The natural period of the structure was 0.57 sec.,i.e., 1.27 times larger than the natural period of 0.45 sec. in the intact situation before repair. After repair, the initial stiffness was smaller than that before repair. The top floor displacement at 200 ton base shear force in the before-repair test was about 30mm. However, it reached about 50mm after repair.

In SPD-7 (320 gal input), maximum response was about 20cm, which was almost the same as the response before repair for the same input earthquake in spite of the degradation of structure stiffness. The maximum base shear capacity of this structure was about 450 ton, which could be reproduced by the calculation based on the plastic behavior of a full scale structure.

The crack pattern in the shar wall after repair was similar to the one before the repair. Before repair the concrete was crushed by compressive failure at the beam lower ends connecting to shear wall. However, after repair works, the crushing of concrete was not observed.

SL-3 was conducted by static loading under a uniform load distribution. This test was controlled by the top floor level displacement angle (R); defined as horizontal displacement at the roof level divided by the total height of the test structure. During the load cycle of R=1/75, the first story shear wall suddenly failed in shear at the base shear force of 600 ton., then this final loading test terminated. At the final stage of this test, the main reinforcement was broken out, and the concrete was crushed along the full span of the first story shear wall. The hysteresis loops of roof displacements are shown in Fig.4.1.

4.2 REPAIR EFFECTS

Although the natural period of the test structure was 0.96 sec. before repair, it was reduced to be 0.6 sec. after repair. This showed that the stiffness of the structure was recovered by repair works. The natural period became 0.5 sec. by the installation of nonstructural elements.

At the four places of the total fourteen beam ends adjacent to the shear wall, the bottom longitudinal reinforcing bars were buckled in SPD-4. Two types of repair were applied to these portions. The crushing of concrete at the repaired portions was not observed throughout the after-repair test series, which means these repairs were considered to be effective for preventing an immature failure of the structure.

Epoxy resin injection into the cracks of floor slabs and beams was done within the area of 1.0 D distance from the surface of columns. In order to examine the difference of effect between full repair and partial repair of epoxy resin, the following support tests were done. The shape of the test specimen and repared portion (hatched part) are shown in Fig. 4.2. These test specimens are just half scale model of full scale beam column joint assembly. The dimension of slab width is equal to the regulated effective width which is almost same in both U.S. Code and Japanese Code. Accoding to the these test results, the recovery of stiffness and strength showed differently between full repair and partial repair for these two specimens as shown in Fig. 4.3. A full-repair specimen recovered almost same stiffness as that before repair and showed higher strength than the virgin strength. It was estimated that epoxy resin injection intro cracks was effective for structural recovery as long as its works were carefully done. The physical origin of repair effects are now being surveyed by the basic tests. Such a cause of effects are analyzed in each case of failure mode; flexural failure, shear flexural failure, shear failure and bond splitting failure.

4.3 NONSTRUCTURAL ELEMENT

The damage of each nonstructural element was observed at every maximum displacement. Typical damages of nonstructural members except for windows are summarized as follows:

a) When the roof-level displacement was 1/1000, cracks occurred around the door openings of the partitions in the fifth story.
b) When the roof-level displacement was 1/500, several doors could not be opened. Cracks were found on walls and around door openings of the partitions GBM-B, MSM-B and MSM-A.
c) When the roof-level displacement was 1/250, many doors of the partition GBM lost their function. Mortar finishings and plaster finishings of partitions in the fifth story began to fall off and door jambs were separated from the partition. When the roof-level displacement was 1/125, boards were separated from furing frames, and the connection between the partition GBM in the third story and that perpendicular to it was damaged. Cracks became large and the separation of the boards was found.
d) When the roof-level displacement was 1/60, the doors in the concrete block wall CB-B and in partition MSM-B showed out-of-plane buckling.

The damage of windows is summarized as follows:

a) There occurred no breakage on the glasses of sliding windows.
b) Cracks were found on the fixed windows with hardening putty when the story drift was around 1/1500-1/500.
c) Cracks were found on the fixed windows with elastic sealant when the story drift was around 1/125-1/73.
d) There was no falling of fragments of broken glass in the case of glass with polyester adhesive films or wired glass.

5. CONCLUSION

This repaired specimen with various nonstructural elements was tested according to the test sequence employed in the first phase test. The overall behavior of the structure after repair was in general similar to that of the before-repair structure. The final Test SL-3 was conducted by static loading under uniform load distribution while SPD tests was under inverted triangular load distribution. During the load cycle with the base shear force of 600 ton, the first story shear wall suddenly failed in shear and the test structure lost its lateral load carrying capacity. Nonstructural elements were damaged in accordance with the drift angle. Nonstructural elements, tightly attached to structural members, suffered damage at much smaller drift angle. Plastic film adhered to the glass pane was found to be effective to keep the broken glass pieces from falling.

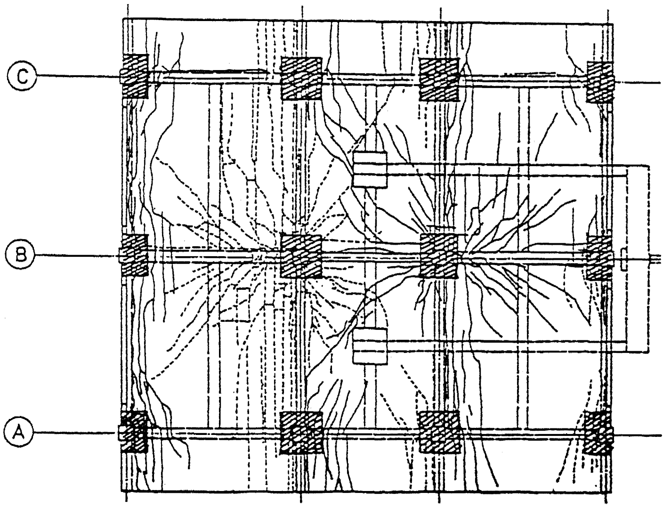
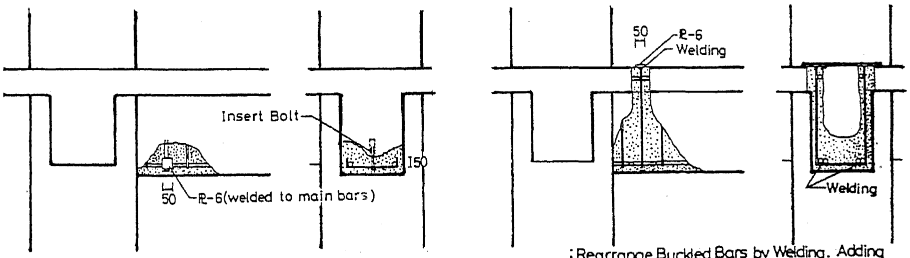


Fig.2.1 Repair Portion by Epoxy Resin



: Plate Welding & Epoxy Mortar Packing

: Rearrange Buckled Bars by Welding. Adding Beam Stirrup and Packing Epoxy Mortar.

Fig.2.2 Typical Repair at Beam Ends

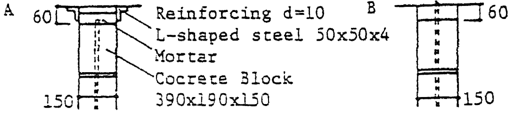
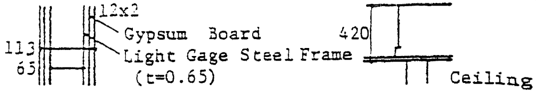
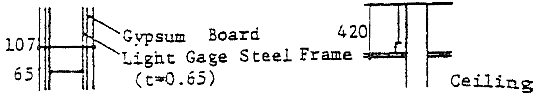
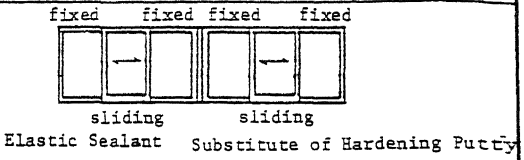
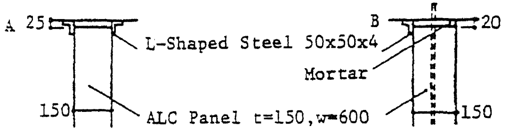
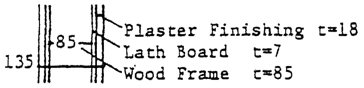
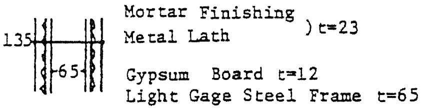
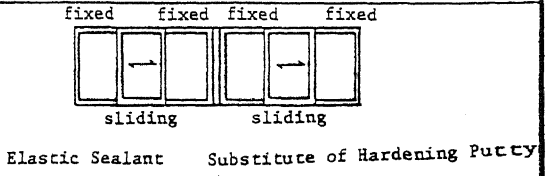
Table 4.1 Dynamic Properties of Test Structure

Test No.	Average-Drift* Angle (rad)	Base Shear (ton)	Period (sec)	Displacement** Amplitude(mm)	Damping Factor(%)
SPD-5	1/7180	26.7	0.57	± 1	13.8
SPD-6	1/333	234.	0.90	± 27	6.6
SPD-7	1/89	452.	1.20	± 70	7.0

* Maximum drift angle (Roof level displacement devided by Total height)

** Free vibration amplitude at which the period and damping factor were determined.

Table 3.1 Details of Nonstructural Elements

	Material	Symbol	Detail
3 F	Concrete Block Masonry	CB	
	Light Gage Steel Frame,Gypsum Board (Floor Slab to Ceiling)	GBM-1	
	Light Gage Steel Frame,Gypsum Board (Slab to Slab)	GBM-2	
	Window Sash	AL-1 AL-2	 AL-1;Float Glass t=5mm+Vinyl Adhesive Tape AL-2;Float Glass t=5mm+Polyester Adhesive Film
5 F	Autoclaved Light-weight Concrete Panel	ALC	
	Wood Frame,Gypsum Lath Board,Plaster Finishing	GBW	
	Light Gage Steel Frame,Metal Lath, Mortar Finishing	MSM	
	Window Sash	AL-3 AL-4	 AL-3;Float Glass t=5mm+Vinyl Adhesive Tape AL-4; Wired Glass t=6.8mm

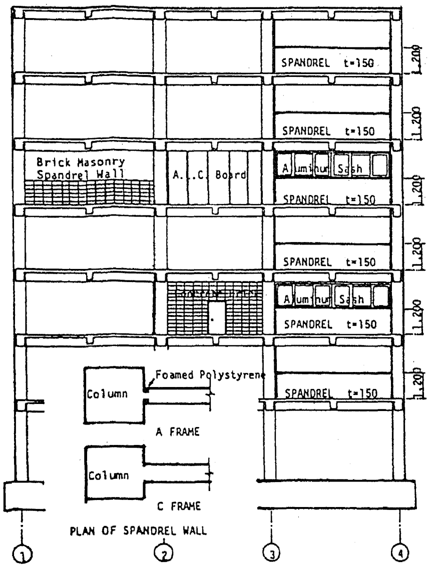
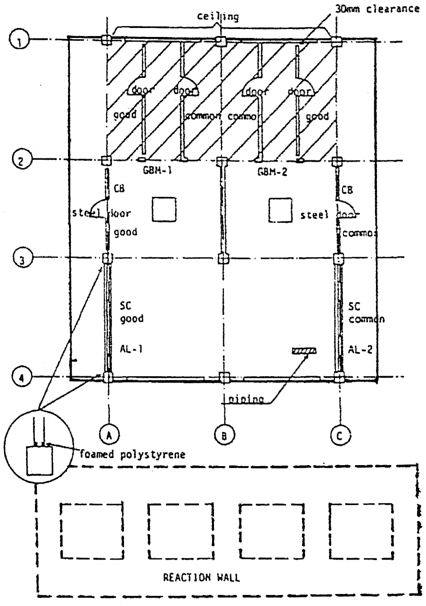


Fig.2.3 Spandrel Installation



Nonstructural Elements (at 3 story)

Fig.3.1 Installation of Partition

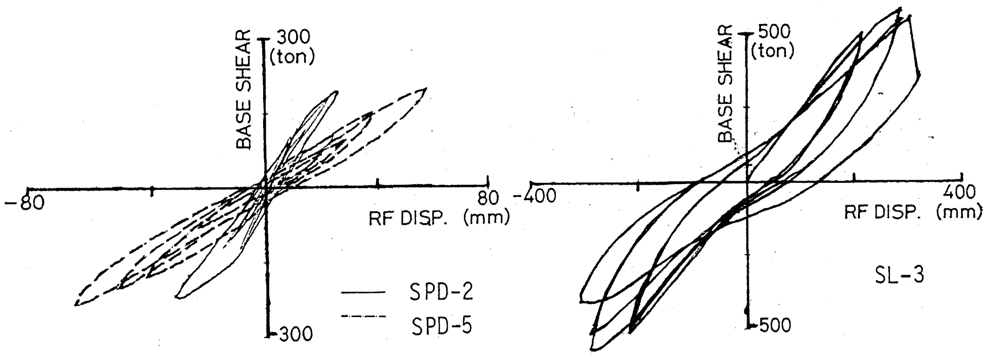


Fig.4.1 Responsed Hysteresis Loops at Roof Floor

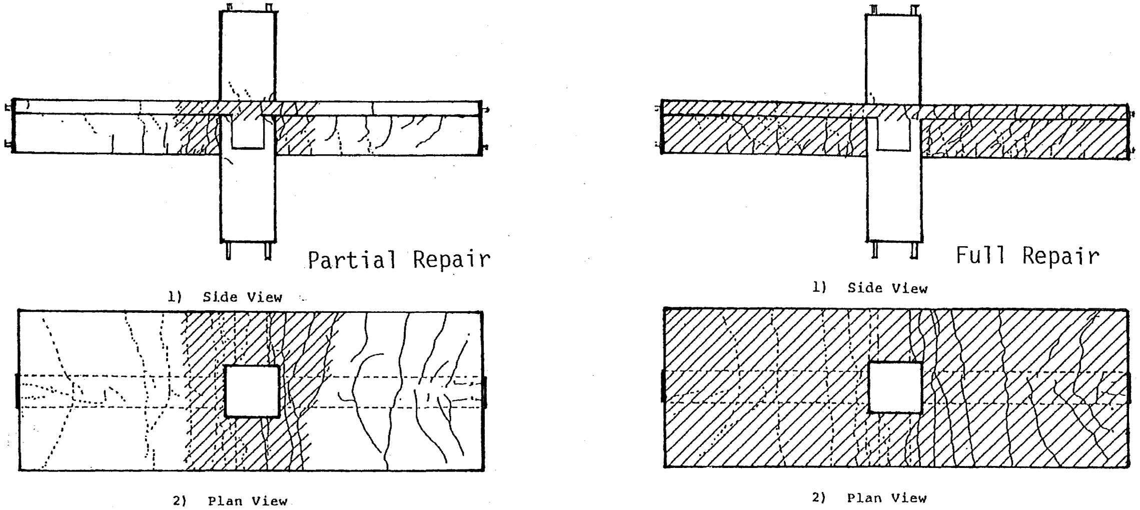


Fig.4.2 Repair Portions of Half Scale Assembly

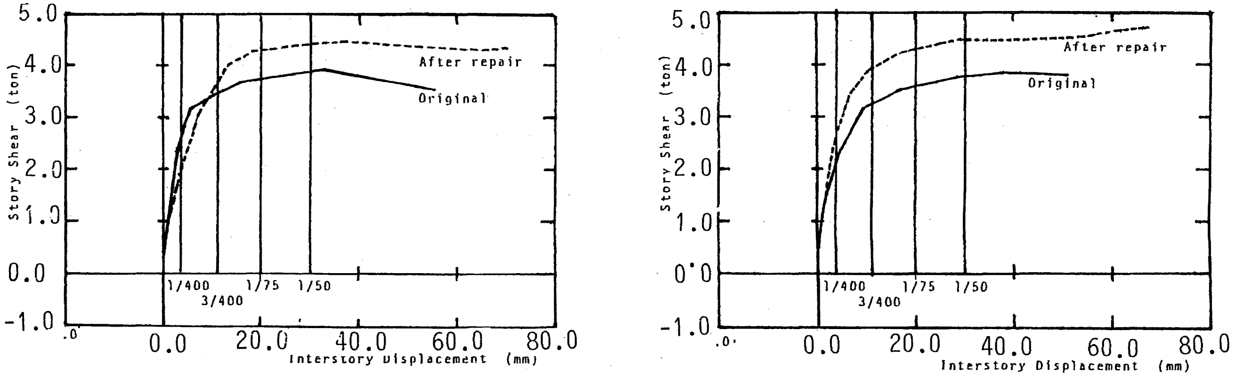


Fig.4.3 Envelope Curves of Story Drift