REHABILITATION OF DAMAGED REINFORCED CONCRETE ELEMENTS : AN EXPERIMENTAL INVESTIGATION,

by

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SUMMARY

24 full-size r.c.columns have been subjected to a constant axial load and a cyclic horizontal displacement simulating strong earthquake loading. The specimens have then been repaired by means of a special rheoplastic cement mortar without variation of outside dimensions, and adopting different procedures for reinforcement rehabilitation, and are now being re-tested under the same loading process.The experiments so far completed show that strength and resistance to degradation of the repaired specimens compare well with the virgin models : this is an interesting result, given the comparative ease and rapidity of this rehabilitation technique.

INTRODUCTION

Typical damages caused by strong earthquakes in reinforced concrete framed structures are the spalling of large concrete zones and the buckling of the longitudinal reinforcement : however, thanks to the relative ductility of reinforced concrete, often the load-carrying structures remain standing, although severely damaged, and their rehabilitation may be economically and socially convenient. On the other hand, there are very few investigations on the effectiveness of such restorations (which should be judged from a comparison of the structural properties, under the same conditions, before the damage and after the repair), and even less(if any) comparative evaluations of the different techniques. Some contributions will hopefully come out of the series of experiments under way in the Structure Laboratory of the Florence School of Engineering, which so far refer to one specific technique but should be extended to other approaches in the near future.

Some laboratory experiments (see e.g.Refs.1,2,3) have indeed already suggested the possibility of obtaining, by substitution and/or addition of concrete in the damaged zones, structural properties that compare well with those of the original structure : these tests are however numerically insufficient, and moreover the test conditions are often rather different from those encountered in real earthquakes.

After the Friuli,Italy earthquake of May,1976, a few buildings were repaired by demolition of the damaged concrete, straightening of the buckled bars, addition of new reinforcement, and final reconstruction of the original concrete section by EMACO, a trademark name of a premixed rheoplastic concrete mortar of high strength and workability. The structures thus repaired survived, without significant damage, the new strong shocks which occurred in September of the same year.

Because of these first positive indications, and of its comparative simplicity and rapidity, this technique of repair is the first examined in our investigation. After a first group of reduced-scale portal frames (5),

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experiments are now being performed on 23 full-scale columns (°), each subjected to a first test producing heavy damage, then repaired and retested, as it will be briefly described in the following Sections. At the time of writing, all specimens have passed the first test, and eight repaired specimens have also been retested (cf.Table III below). The tests of the first four virgin and repaired specimens have already been reported in Ref. 6 ; the complete investigation shall be the object of a full-length successive paper (7).

SPECIMENS AND TESTING

Most earthquake damages in r.c.frames occur near the ends of the columns, especially when none or insufficient provisions for earthquake resistance have been taken. The specimens used in this investigation, and already described in Ref.6, were designed to reproduce this "strong-beam weak-column" situation, in which rehabilitation is easier in real instances :

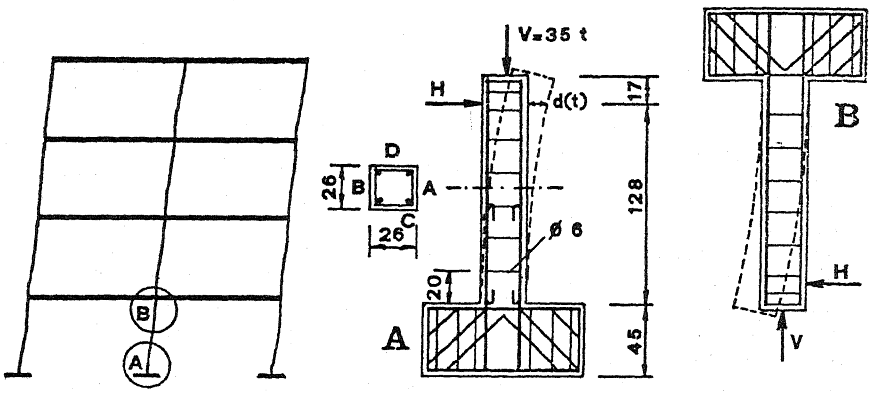

FIG.1 : Test specimens (Type A and Type B).

namely (Fig.1), they are cantilever columns, all with the same geometric dimensions and reinforcement arrangement (but with 4 longitudinal bars of either 12,16 or 20 mm.diameter),cast together with a stiff beam stub,which during the test is rigidly bolted on the testing bench; the free length of the columns is about half the net length of an usual building column, so that the ratio bending moment/shear force in the specimens is approximately the same as in the most common frames. Moreover, the longitudinal reinforcement has hooked lap splices in 12 specimens (Type A specimens) and is continuous in the other 11 (Type B specimens), to reproduce the usual constructional difference between bottom and top column joints and to study its possible effects.

Throughout this research, each specimen is indicated by the type of reinforcement (A or B), followed by the longitudinal bar diameter in mm. (12,16 or 20) and a serial number (1,2,3 or 4); the final letter which is seen on some photos indicates the side under view (cf.section in Fig.1).

The mechanical properties of the specimens materials are summarized in Tables II and III.

The models are loaded by two double effect servo-controlled hydraulic

(°)One of the 24 original specimens was put out of service because of an initial wrong load application.

TABLE I : REINFORCEMENT.			
Diameter (mm)	Yield stress (Kg/mm^2)	Ultimate stress (Kg/mm^2)	Ultimate elongation (%;5 Ø)
Ø 12	42,0	60,2	26,7
Ø 16	46,5	71,8	17,5
Ø 20	47,5	74,4	23,7

TABLE II : CONCRETE					
Material	After days	Characteristic strength (Kg/cm^2)	Bending tensile strength (Kg/cm^2)	Static elastic modulus (Kg/cm^2)	Dynamic elastic modulus (5) (Kg/cm^2)
Type "A" models	7	328 (2)	--	--	--
	28	515 (2)	54 (4)	293.000	483.000
Type "B" models	7	350 (2)	--	--	--
	28	548 (2)	60 (4)	307.000	504.000
Repairs Emaco S 88 mortar (1)	7	750 (3)	88	--	--
	28	950 (3)	96	380.000	--

(1) manifactured by Mac Mediterranea, Treviso (Italy)
(2) obtained on 15 x 15 x 15 cm cubes
(3) obtained on 4 x 4 x 16 cm prisms
(4) obtained on 16 x 16 x 65 cm prisms
(5) obtained from ultrasonic testing

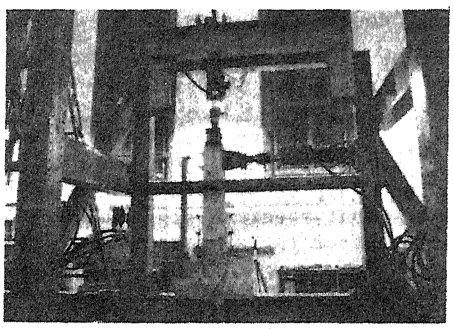

FIG.2 : Test setup

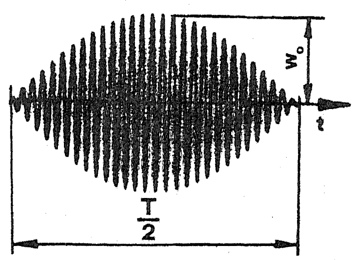

FIG.3 : Horiz.load history

jacks (Fig.2), which apply respectively a constant compression of 35 tons (corresponding to an average stress of 50 kg/cm^2 approximately) and a transverse cyclic displacement, which varies during the test according to the law (Fig.3)

$$w = w_o \sin \frac{2\pi t}{T} \sin \frac{2\pi t}{T_1} \quad ; \quad 0 \leq t \leq \frac{T}{2} \ ; \ T_1 << T$$

This simple law apparently retains the main features of an earthquake loading history (8), namely an alternating action whose intensity increases first, then decreases. It has the added advantage, essential to compare results, of being reproducible in successive tests; also, the control of displacements (rather than the more usual force control) appears more realistic in testing of structural elements. Experimentally, this process is obtained by adding two sine waves of slightly different periods : thus,the value of T_1 is practically the same (3.3 sec) in all tests, but the control of T is much less accurate, and the actual number of cycles varies from test to test (cf.Table III). The magnitude of the applied displacements is so large that in all tests the specimen strength begins decreasing well before the maximum displacement w_o is reached; inertia effects are negligible, because of the relatively low frequency.

One specimen of each group is tested statically, by either a monotonically increasing displacement or a very slow large displacement cycle.

REHABILITATION AND RE-TESTING OF DAMAGED SPECIMENS

At the end of the first test of each specimen, structural damage is evident : the concrete has cracked and spalled, the longitudinal bars have buckled into permanent waves (Fig.4). Then, the concrete is either demolished all around the damaged zone leaving the original concrete core intact (Fig.5A) or, when the core has been more severely damaged, completely removed (Fig.5B); the reinforcement is repaired according to different procedures, diagrammatically indicated in Fig.6, namely

R1 : the longitudinal bars are flame-heated and straightened;
R2 : besides straightening as in R1, three 6-mm.dia.stirrup ties are added;
R3 : stubs of virgin bars are welded to the ends of the buckled wave of the original reinforcement, which afterwards is cut away;
R4 : besides substitution of buckled bar portions as in R3, three ties are added as in R2;
R2',R4' : like R2 and R4 respectively, with double hoop ties.

Other reinforcement rehabilitation procedures may be tried in the successive tests. Examples of repairs type R2 and R4 are shown in Fig.5.

Finally, the original concrete section is reconstructed by a cast of EMACO and, after maturation, the repaired specimens are subjected to the same loading history as the virgin ones. Two examples of specimens after the second test are shown in Fig.7, but note that specimen B16/3 has been subjected to extra constant-amplitude cycles after the standard test,until a reinforcing bar broke.

TEST RESULTS

The forces in the jacks, and the displacement of the specimen top are recorded continuously in each test; the bending moment in the fixed-end

FIG.4 : Two specimens (A16/2; B16/3) after first test.

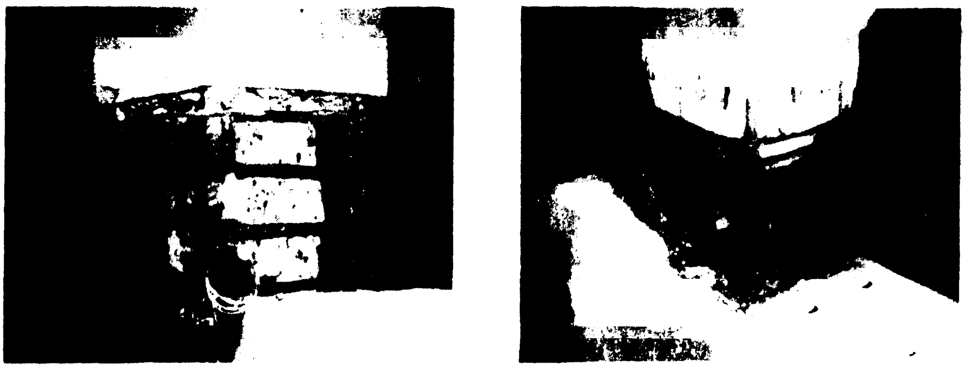

FIG.5 : Two repaired specimens (A16/2; B16/3) before casting of EMACO.

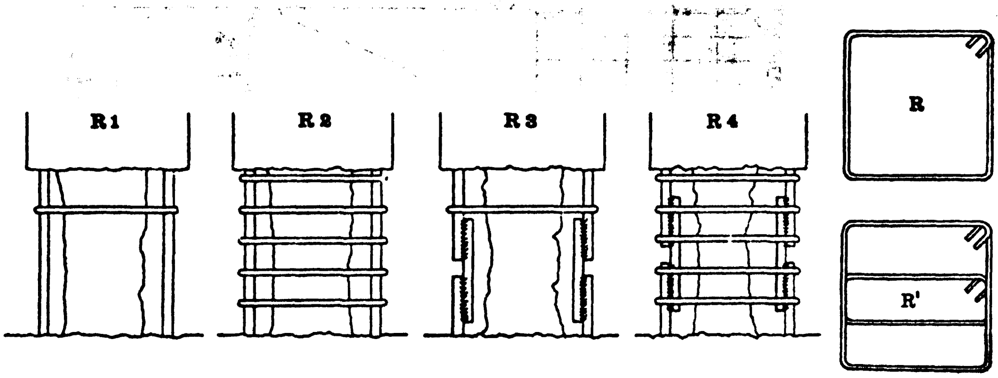

FIG.6 : Reinforcement rehabilitation procedures (diagrammatic).

column section is then calculated, along the experimental record, taking into account also the force in the vertical jack : a typical example of moment-displacement cycles obtained in this way, is shown in Fig.8.

Two static test records are shown in Fig.9, while Fig.10 shows examples of a more synthetic graphical presentation of the dynamic tests, which is obtained by connecting the black dots indicated in Fig.8 (i.e.the vertices of each cycle) and presents in a more evident form the main features of each test. (Other analogous examples can be found in Ref.6.)

Table III summarizes the main test conditions and results so far obtained : more complete informations, including those derived from the record of strains in the concrete and reinforcement, will be included in the final paper (7), to which all conclusions are left.

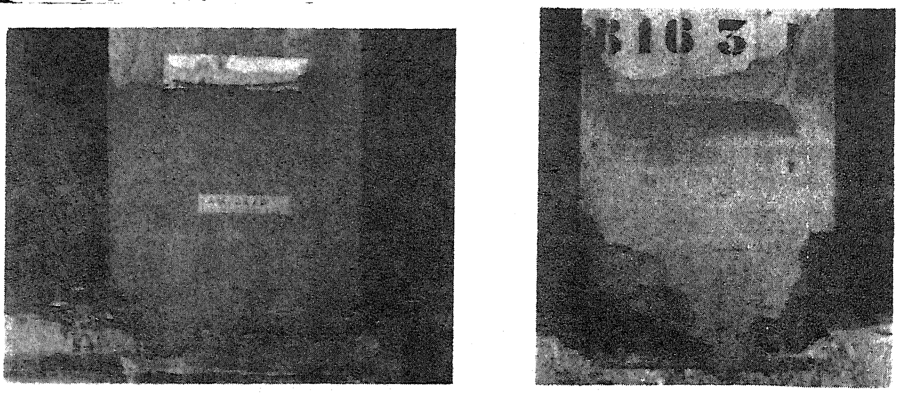

FIG.7 : Two repaired specimens (A16/2; B16/3) after retesting.

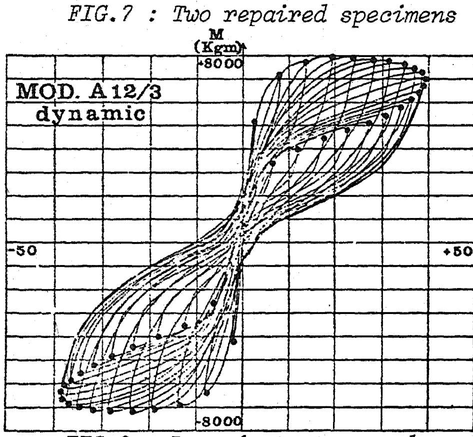

FIG.8 : Dynamic test record

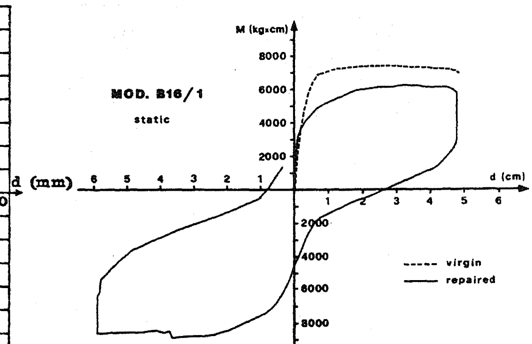

FIG.9 : Static test records

In the little space available here, it is only possible to remark that virgin and repaired specimens, subjected to the same axial load (constant) and transverse displacement cycles (corresponding to a maximum ductility factor of about 4), support moments of the same order of magnitude, although the original concrete was of a very high quality (Table II). Therefore, the effectiveness of rehabilitations with rheoplastic mortar is so far confirmed by our experiments.

Another important result appears the experimental demonstration that specimen degradation with repeated deformations (measurable by the vertical width of the ideal "cycles" of Fig.10) is greatly reduced by the addition of extra stirrup ties, which prevent buckling of longitudinal bars.

TABLE III

	VIRGIN SPECIMENS					REPAIRED SPECIMENS					
	Test	No of cycles	Wo (mm)	H max (kg)	$\varepsilon_b$max (‰)	Type of repair	Test	No of cycles	Wo (mm)	H max (kg)	$\varepsilon_b$max (‰)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A12/1	S	-	54	5340	3,1						
A12/2	D	25	38	>5090	3,0						
A12/3	D	21	39	5590	3,5						
A12/4	D	37	37	5640	-						
B12/1	D	31	39	> 4600	-						
B12/2	D	30	39	5609	-	R2'	D	32	40	5563	3,1
B12/3	D	32	40	5511	-						
B12/4	S	-	54	5478	-						
A16/1	S	-	54	4700	-	R1	D	48	43	5850	-
A16/2	D	35	40	5020	-	R2	D	28	42	5400	-
A16/3	D	26	39	5690	-	R3	D	27	42	5940	-
A16/4	D	26	40	5380	-	R4	D	25	42	5570	-
B16/1	S	-	48	5150	3,4	R2	S	-	59	5970	> 3,4
B16/2	D	28	43	5480	3,2	R2'	D	34	34	5150	4,7
B16/3	D	29	43	< 6280	3,4	R4	D	30	36	5450	4,3
A20/1	S	-	53	8272	3,2						
A20/2	D	30	-	8050	3,1						
A20/3	D	30	38	-	3,4						
A20/4	D	31	37	8685	3,3						
B20/1	D	26	-	7512	3,5						
B20/2	S	-	55	8501	3,3						
B20/3	D	28	-	> 7142	3,4						
B20/4	D	29		7716	3,6						

NOTES

columns (2)(8): S: static
D: dynamic(Fig.3)

columns (5)(11): max.exptl.horiz. force(corrected)

columns (6)(12): max.exptl.long. concrete strain (fixed-end section)

column (7) : see Fig.6

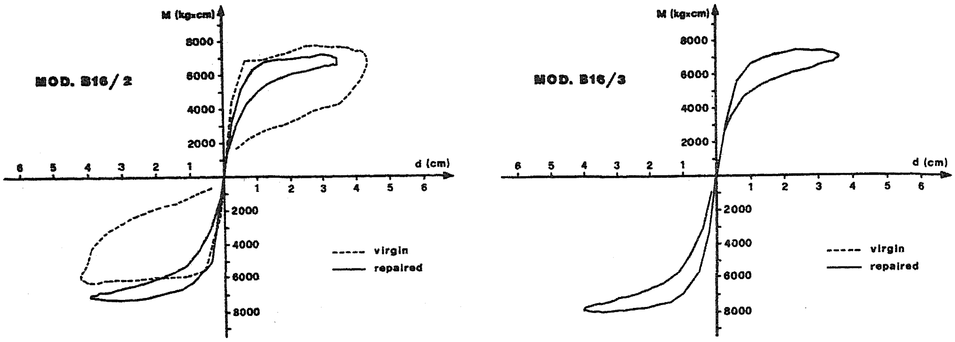

FIG.10 : Peak end moment M vs.peak applied displacement $d = w_o \sin\frac{2\pi t}{T}$

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