Repair techniques of reinforced concrete beam - column joints

Autor(en): **Migliacci, Antonio / Antonucci, Rodolfo / Avramidou Maio, N.**

Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **46 (1983)**

PDF erstellt am: **23.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-35869

Repair Techniques of Reinforced Concrete Beam - Column Joints

Techniques de réparation de noeuds poutre-colonne en béton armé

Reparatur von Rahmenknoten aus Stahlbeton

Antonio MIGLIACCI
Prof.
Polytechnic of Milan
Milan, Italy

Rodolfo ANTONUCCI
Prof.
Univ. of Ancona
Ancona, Italy

N. AVRAMIDOU MAIO
Prof.
Univ. of Florence
Florence, Italy

Paolo NAPOLI
Prof.
Univ. of Venice
Venice, Italy

A. SAMUELLI FERRETTI
Prof.
Univ. of Rome
Rome, Italy

Giovanni VIA
Prof.
Univ. of Rome
Rome, Italy

SUMMARY

Tests performed on specimens representing subassemblages of multi-storey r.c. frames are presented, and first results are discussed. Virgin specimens are stressed by means of cyclically imposed displacements. After repair, identical straining histories are applied. Some repair techniques, selected among the most commonly used, are examined. Results are discussed, with reference to a few parameters representative of strength and energy dissipation capacity.

RESUME

La communication présente les premiers résultats d'un programme de recherches sur des modèles structuraux de parties de portiques à plusieurs étages en béton armé (noeuds poutre-colonne). Les essais sont conduits sur les modèles originaux soumis à des sollicitations alternées et sur les mêmes modèles après réparation. Quelques techniques de réparation ont été examinées parmi celles couramment employées. Les résultats sont discutés en fonction des paramètres représentant la résistance et la capacité de dissipation.

ZUSAMMENFASSUNG

Es werden die Ergebnisse aus Versuchen an Probekörpern, die Knoten eines mehrstöckigen Stahlbetonrahmens darstellen, vorgestellt. Die Probekörper erfuhren vor und nach ihrer Verstärkung die gleiche Wechselbeanspruchung. Es wurden einige der üblichen Reparaturmethoden unteruscht. Die Ergebnisse werden hinsichtlich einiger für die Festigkeit und Energiedissipation bedeutungsvoller Parameter diskutiert.

AIM OF THE RESEARCH

Technical development as well as economy evolution of the last years have stressed the opportunity of retrofitting existing buildings, expecially those not designed to resist earthquakes, and salvaging the ones damaged in the struck areas.

The studies concerning the efficiency of the different repair and strengthening techniques are still, as yet, not so numerous neither so systematic as the researches concerning the behaviour of the virgin structures or structural elements. The present work is then aimed at acquiring an extensive knowledge of the efficiency of local repairs on r.c. elements.

The research has been promoted by C.N.R. (Italian National Research Council) and has been based on the cooperation among five laboratories of different universities (*). Gathering of research force sufficient for the task at hand was made possible in this way; moreover the coordination attains the results of homogeneity of experimental set-ups and techniques, as well as analysis and evaluation of the results.

EXPERIMENTAL PROGRAM

Damages in an ordinary r.c. frame subjected to earthquake have a tendency to take place in the joints and in the extremities of the surrounding members.

The present work is concerned with exterior joints only; the specimens are ideally obtained by extracting from a frame an element defined by two half columns and a length of a beam, thus obtaining a **T**-shaped element which is almost commonplace in similar tests (Fig. 1).

The characteristics that diversify the specimens tend to reproduce the situations really found in structures, not necessarily well designed and detailed. Sufficient as well as poor reinforcement percentages have been provided; simulation of lower or upper storey joints was obtained by vertically stressing the columns in two different degrees.

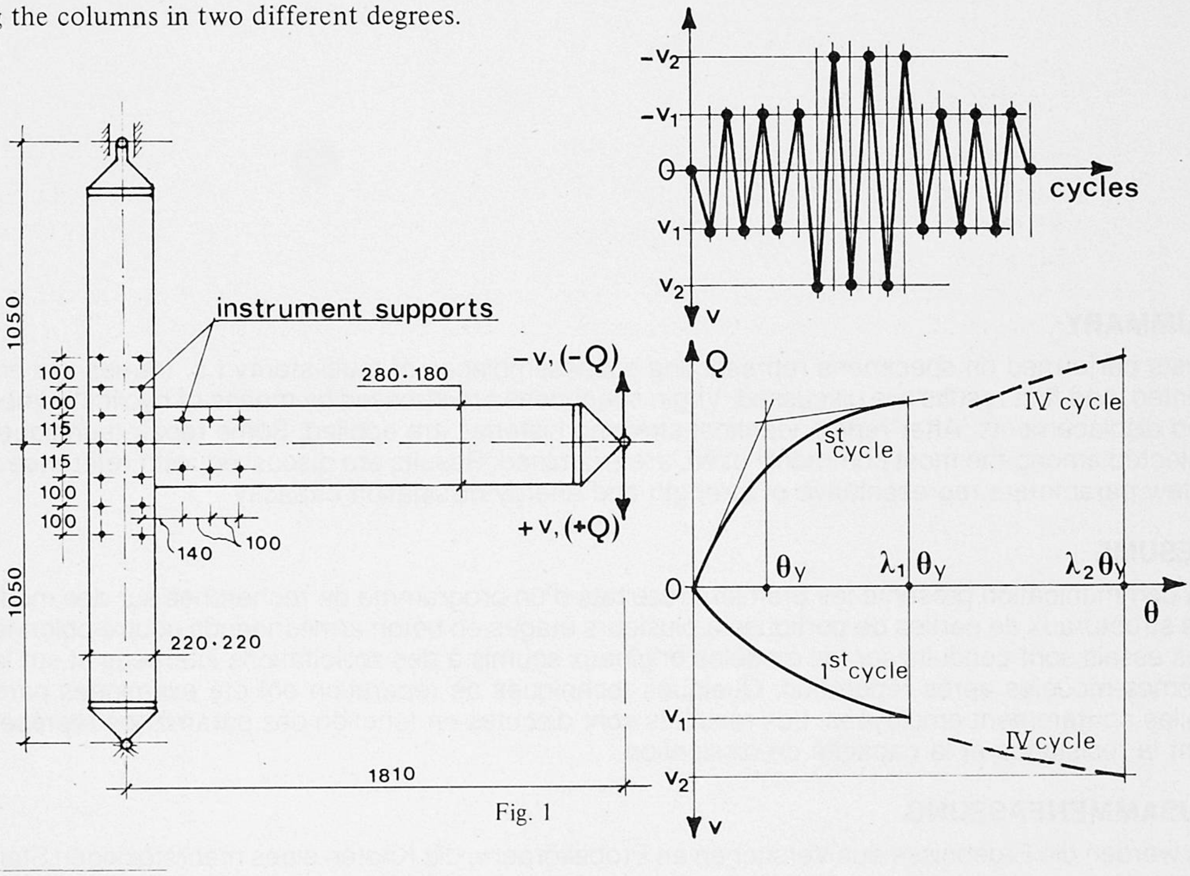

Fig. 1

(*) The laboratories that performed the tests (in the following they shall be indicated by the initials) are: Polytechnic of Turin - Engineering - (TO); - University of Florence - Architecture (FIa); - of Ancona (AN); - of Rome, Architecture (RMa); - Engineering (RMi).

Reinforcement was designed in order to concentrate damages either in the joint or in the member ends. Repair techniques must, of course, be adapted in accordance with the location and importance of damages.

As a consequence the specimens are classified on the basis:

I) of the section in which 'plastic hinges' are designed to occur, that is in the columns -**P**-; in the beam -**T**-; in the joint -**N**-.
II) of the transversal reinforcement, that is light -**R**- or strong -**F**-.
III) of the value of axial load in the column, that is light -1- or heavy -2-.

The specimens have been scaled down to 2/3 with respect to a typical actual structure; in this way the scale effect is practically negligible.

The tests are performed by cyclically applying a displacement $\pm$ **v** at the free end of the beam, by means of a hydraulic actuator operating statically.

The strain as well as the start and spreading of damages are of a level that can be found in actual structures struck by earthquake.

Preliminary tests suggested to assume the following straining procedure:

the governing factor is the strain (say the curvature ϑ_y in the critical section) at the knee of the diagram corresponding to the yielding of the reinforcement or at the appearance of other causes of non linearity. Straining is then increased until a curvature $\lambda_1 \cdot \vartheta_y$ is reached: deflection of the beam is recorded, at a value called $\mathbf{v}_1$. Three cycles from $+\mathbf{v}_1$ to $-\mathbf{v}_1$ are then imposed. The fourth cycle is again governed by the curvature, $\lambda_2 \cdot \vartheta_y$. The corresponding deflection $\mathbf{v}_2$ is imposed alternately during cycles 4 to 6, then again $\pm \mathbf{v}_1$ during cycles 7 to 9. Repaired specimens undergo the same sequence $\pm\mathbf{v}_1$, $\pm \mathbf{v}_2$, $\pm \mathbf{v}_1$.

Instrumentation consists mainly in displacement meters fixed on rods deeply embedded in concrete, in order to avoid loss of readings due to spalling. Extensometric base lengths are about one half the depth of the column.

REPAIR TECHNIQUES

Repair techniques fall into two main categories. The first one, after removal of crushed concrete and cleaning of surfaces, consists in restoring the damaged segments by means of different materials and techniques with or without previous injection of epoxy resin in the cracks. Adding of new steel ties is applied in a few cases.

The second technique, after restoring by means of ordinary sand and cement mortar, consists in a strengthening of the joint by means of steel angles and plate lacings, which are prestressed in some cases (Fig. 2).

In such cases the angles, sand-blasted at the interior surface, are glued to the concrete by means of epoxy adhesive; after welding, lacings are heated to bright red temperature (~ 850 °C) in the middle segment (about 1/4 of the length), thus obtaining normal stresses of 120 **MPa** average value.

Restoring of damaged segments when the first technique is applied is obtained by means of: i) cement mortar with the addition of plasticizer non-shrink admixtures plastered or cast in formworks ii) epoxy mortar, plastered on surfaces.

Injection of cracks is obtained by pressure or vacuum procedure.

The different techniques applied are reported in the 7th column of Table 1.

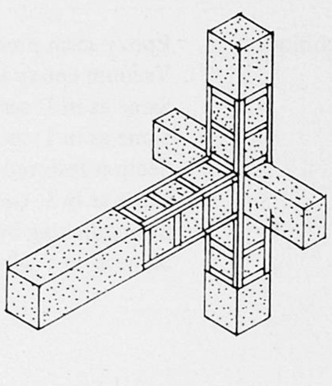

Fig. 2

Table 1

1	2	3	4		5	6	7	8	9	10	11
type	axial stress [MPa]	lab.	specimen identific.		v [mm]	damage level	repair technique	$\frac{\Sigma \lvert Q_r^{(i)} \rvert}{\Sigma \lvert Q_0^{(i)} \rvert}$	$\frac{tot.\ E_r}{tot.\ E_0}$	$\frac{Q_r^{(9)}/Q_r^{(1)}}{Q_0^{(9)}/Q_0^{(1)}}$	$\frac{E_r^{(9)}/E_r^{(1)}}{E_0^{(9)}/E_0^{(1)}}$
TT	4,19	TO	1	1 TT	40-73-40	A	1	0.98	0.71	1.12	1.63
		TO	2	2 TT	40-73-40	A	1	1.07	0.84	1.03	1.85
		FI a.	3	2 TT	54-75	D	6	1.13	0.79	–	–
		AN	4	1 TT	47-116	D	6	1.04	0.83	–	–
PF 1	4,19	TO	5	1 PF 1	59-86-59	B	3	1.15	0.91	1.22	1.83
		TO	6	2 PF 1	59-86-59	B	4	1.18	1.10	1.25	1.41
		RM a.	7	3 PF 1	35-70-35	A	1	1.03	0.89	1.22	1.58
PR 1	4,19	TO	8	1 PR 1	50-65-50	B	3	1.25	1.04	1.24	1.44
		FI a.	9	2 PR 1	27-54-27	A	2	1.03	0.98	1.21	1.59
		FI a.	10	4 PR 1	39-57-39	B	6	1.09	1.12	1.06	1.63
		RM i.	11	1 PR 1	48-62	C	7	1.03	1.06	–	–
		RM i.	12	2 PR 1	47-67	C	8	1.38	1.41	–	–
PF 2	8,38	TO	13	1 PF 2	57-85-57	B	3	1.22	1.08	1.18	2.00
PR 2	8,38	TO	14	1 PR 2	32-49-32	B	3	1.16	0.70	1.16	0.73
NF 1	4,19	RM i.	15	13 NF 1	75-117-75	C	7	0.91	1.16	2.49	1.86
		RM i.	16	14 NF 1	83-106-83	C	8	1.03	1.41	1.50	2.30

Damage level:
- A Crack opening up to 4 mm, moderate crushing of concrete cover.
- B Spalling of cover, moderate crushing of concrete core.
- C Extensive crushing of core.
- D Same as in C, with buckling of reinforcement bars.

Repair techniques:
1. Epoxy resin pressure injection.
2. Vacuum epoxy injection, with polyethylene foil jacket.
3. Same as in 1; section restored by means of epoxy concrete.
4. Same as in 1; section restored by means of cement concrete with admixtures.
5. Section restored by means of cement concrete with admixtures (no injection).
6. Same as in 5, ties added.
7. Strengthening by means of corner profiles and lacings.
8. Same as in 7; glued corners, heat-prestressed lacings.

RESULTS

In column 5 of table 1 displacements v_1 and v_2 are reported; in column 6 the damage level, as specified at the bottom of the table. Remaining columns from 8 to 11 contain indexes that have been chosen as representative of the efficiency of the adopted repair technique (suffix **o**, virgin specimen; suffix **r**, repaired specimen).

The index reported in column 8 evaluates the strength of the repaired specimens with respect to the one of the virgin ones. Namely such index is the ratio between the sum $\Sigma\ |Q_r^{(i)}|$ of the absolute values of the beam end responses $Q_r^{(i)}$ at the imposed displacements $\pm v_1$ and $\pm v_2$ of the repaired specimen, and the analogous sum $\Sigma\ |Q_0^{(i)}|$ of the responses $Q_0^{(i)}$ by the virgin specimen.

The column 9 contains the ratios between the cumulative energies dissipated in the whole series of applied cycles:

$$I_9 = \frac{\text{tot. } E_r}{\text{tot. } E_0} = \frac{\Sigma \int Q_r \, dv}{\Sigma \int Q_0 \, dv}$$

The index in column 10 gives an idea of the decaying of the strength along the applied straining history, as the fraction of the strength of the last cycle with respect to the strength of the first, $Q_r^{(9)}/Q_r^{(1)}$, in the repaired specimen divided by the same fraction as computed for the virgin one.

In column 11 an analogous index, this time concerning the energies dissipated during last and first cycles is reported.

It is of some interest to give more detailed information with regard to the variation of strength and dissipated energy during the straining history. In the Fig. 3 the values of the ratio between $Q_r^{(i)}$ and $Q_0^{(i)}$ are plotted against the number **i** of cycles for the most representative cases.

In Fig. 4 similar ratios are contained, concerning the energy dissipated in each cycle.

In Fig. 5 the values of $Q_r^{(i)}$ and $Q_0^{(i)}$ are plotted against **i**.

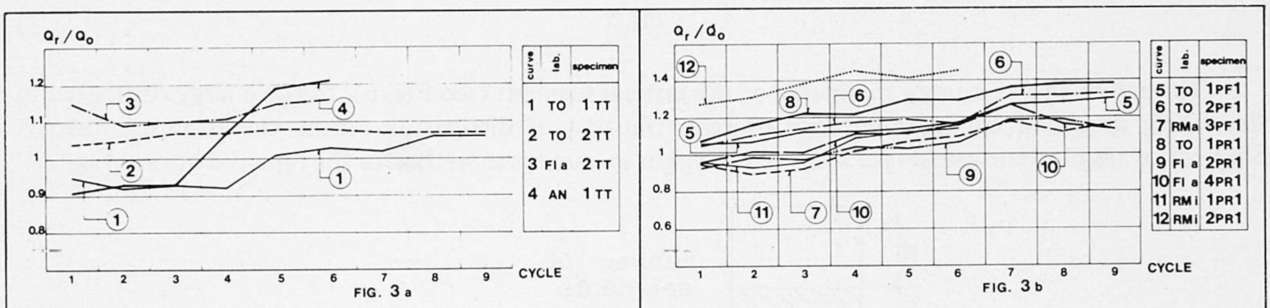

Fig. 3

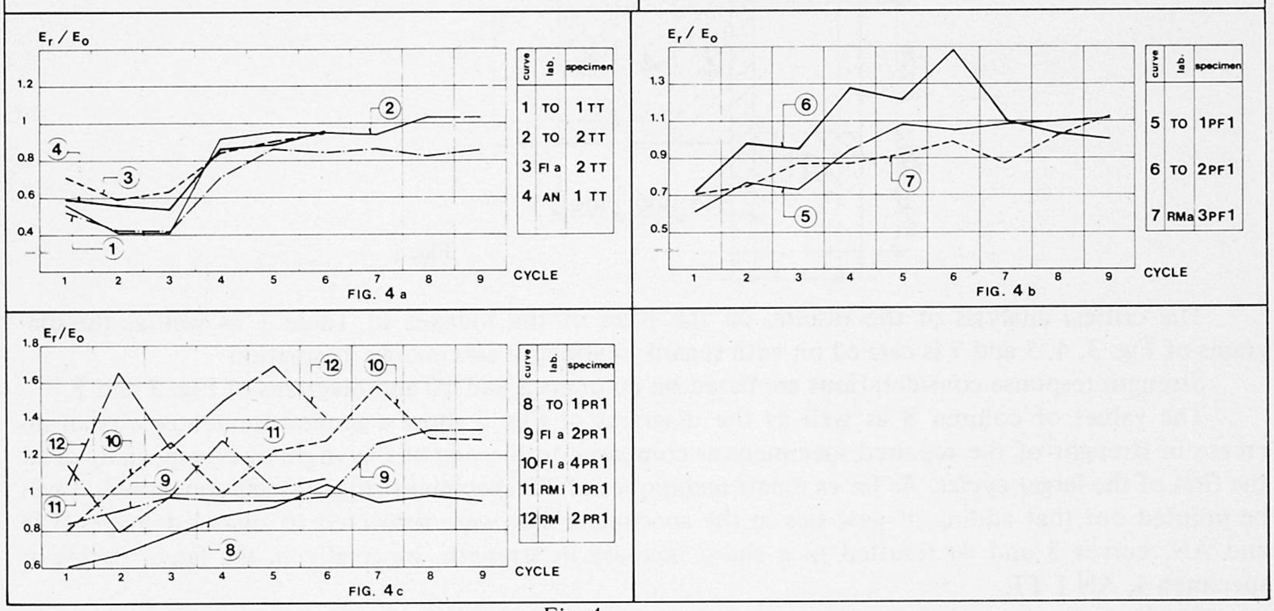

Fig. 4

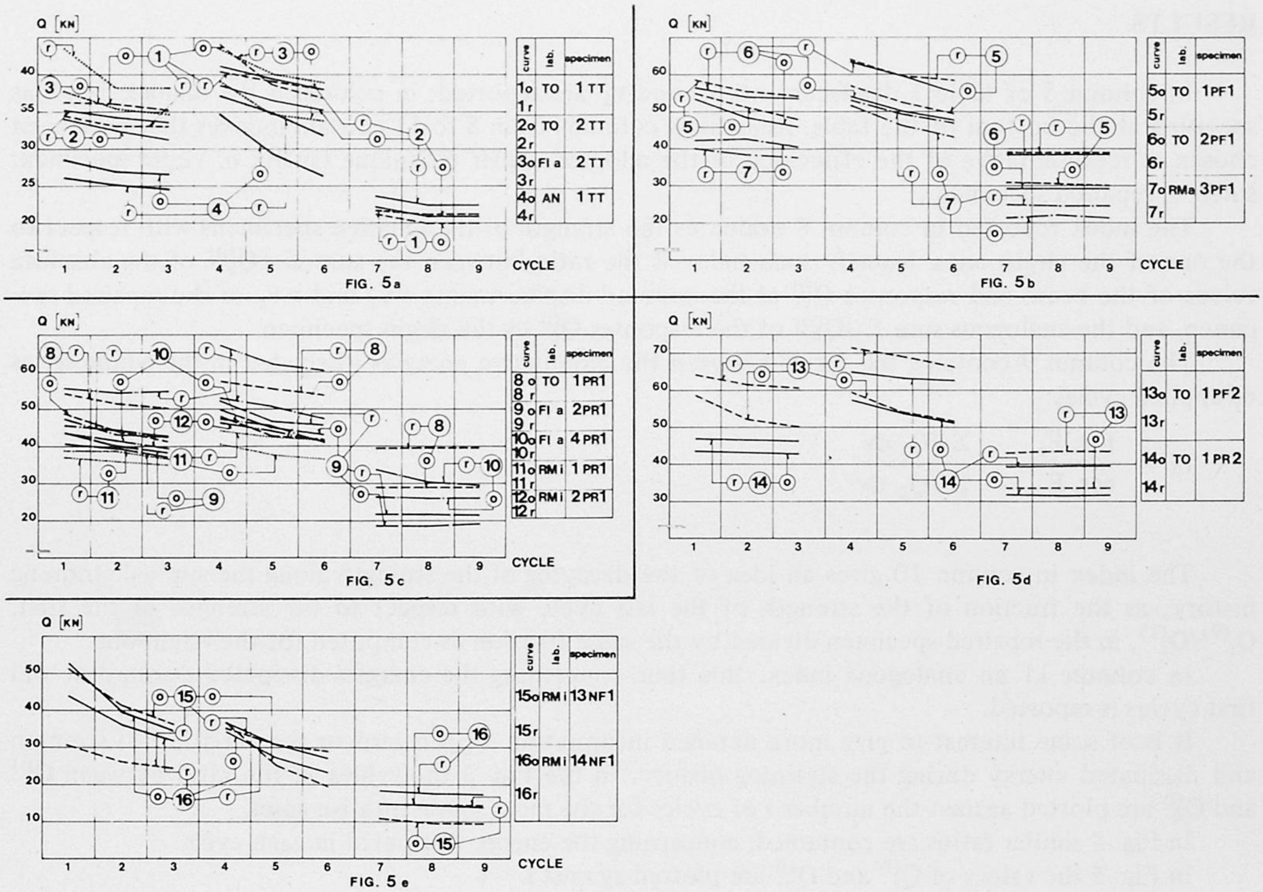

Fig. 5

The ratios of the energy dissipated at the critical segment (see Fig. 6), to the energy dissipated in the whole specimen are representative of redistribution of dissipation during the straining history. Such ratios are plotted against **i** for some of the virgin specimens as well as for the repaired ones in Fig. 7.

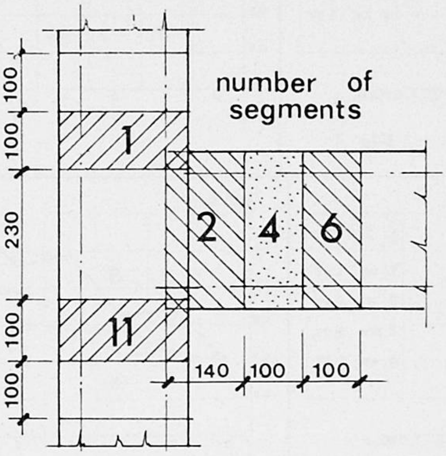

Fig. 6

The critical analysis of the results, on the basis of the indexes of Table 1 as well as the diagrams of Fig. 3, 4, 5 and 7 is carried on with regard to strength and energy dissipation.

Strength response considerations are based on columns 8 and 10 and diagrams of Fig. 3 and 5.

The values of column 8 as well as the diagrams of Fig. 3 show a general trend towards an increase in strenght of the repaired specimens as compared to the one of the virgin ones, especially after the first of the larger cycles. As far as repair techniques of **TT** specimens (Fig. 3a) are concerned, it can be pointed out that adding of new ties in the specimens that were subjected to greater damages (FIa and AN, curves 3 and 4) resulted in a sharp increase in strength, especially in the larger cycles of specimen 4, AN 1 TT.

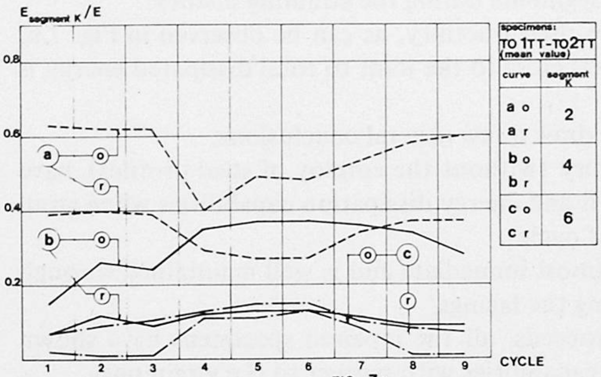

FIG. 7a

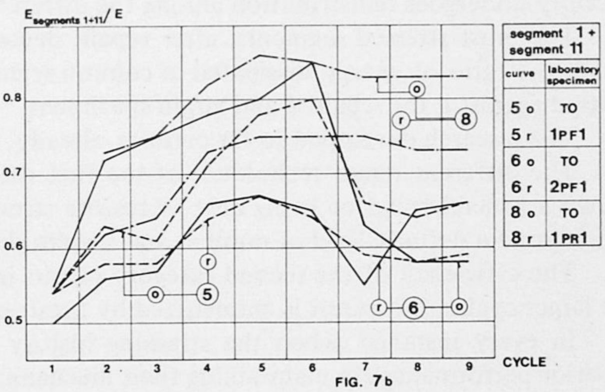

FIG. 7b

A good agreement can be found among results of tests on specimens **P**, type **F** and type **R** (Fig. 3b), with repairs of type 1, 3 and 4 (epoxy resin pressure injection, curves 5, 6, 7, 8) as well as of repair of type 2 (epoxy resin vacuum injection, curve 9), regardless of the material employed in restoring the section. Similarly, a good agreement exists between the results of tests on specimens repaired with steel profiles without prestressing, (curves 10 and 11, FIa and RMi). When the lacings are prestressed the response in strength is significantly improved (curve 12, RMi).

More information concerning the development of strength response can be desumed from Fig. 5, containing the readings of the $Q_0^{(i)}$ and $Q_r^{(i)}$ forces at the beam end, grouped in five different diagrams. The groups are composed of the results of the **TT**, **PF1**, **PF2** together with **PR2** (high axial stress on the column) and **NF1** specimens. For instance, the results concerning the **NF1** specimens repaired following the techniques of passive or prestressed lacings, show that the response of the repaired specimen is less than the response of the virgin one as far as the first three low amplitude cycles are concerned, while the opposite is true when the larger cycles are applied. Performance of the prestressed specimen is better in both phases.

The indexes contained in column 10, being always greater than unity, show that the repaired specimens have a better capacity of "overall maintenance" of strength than the virgin ones.

As far as energy dissipation is concerned, columns 9 and 11 as well as diagrams in Fig. 4 and 7 are provided for a critical analysis.

The values of the index in col. 9 together with the diagrams in Fig. 4 show a general trend of a lesser capacity of dissipating energy in the repaired specimens as compared to the one exhibited by the virgin ones; this is true in a higher degree during the first low-displacement cycles. When steel profiles are employed the opposite is true, the energy dissipated being larger along the whole straining history.

Considering the repairs carried on **TT** specimens (Fig. 4.a, curves 4 and 10), the adding of ties improves the capacity of dissipation since the very beginning.

For specimens tested at **TO** laboratory (curves 1 and 2, low level damage and epoxy injection of cracks), overall dissipated energies during the whole test of the repaired specimens were very close to the values of the virgin ones.

As far as specimens of the **P** type are concerned, with the exception of the ones repaired by means of steel profiles (curves 10, 11 and 12 of Fig. 4.c), all the others, regardless of the particular repair technique employed, show an increasing dissipation capacity of the repaired specimen with respect to the virgin one. As a consequence, the values of the index in column 11 are greater than unity.

A good agreement exists between the performances of repairs by means of non-prestressed steel profiles obtained at **FIa** and **RMi** laboratories, while the prestressed one show a superior performance even in terms of dissipation capacity.

More information concerning energy dissipation can be obtained examining the diagrams of Fig. 7.a, concerning the tests conducted at **TO** laboratory on **TT** specimens. It can easily be seen that the energy dissipated at the most stressed segments is greater in the virgin specimen than in the repaired one. The opposite in true when the less stressed segments are concerned. This fact means that the ductility undergoes redistribution among the different segments during the straining history.

The most stressed segments, after repair, decrease their ductility, as can be observed in Fig. 7.b, where the ratio of energy dissipated in column segments close to the joint to total dissipated energy is plotted against **i**, for repaired and virgin specimens.

The research developed so far permits, already, to draw a few general conclusions.

The different repair techniques of the first category (without the employ of steel profiles), have shown a general trend of being able to restore strength and energy dissipation capabilities when strained beyond a definite level of number and amplitude of cycles.

The efficiency of the second category repairs is almost immediate and is well maintained through the larger cycles; this result is emphasized by prestressing the lacings.

In every instance, when the straining history proceeds, all the repaired specimens have shown superior performances in maintaining their mechanical capabilities with respect to the virgin ones.

REFERENCES

General Reports:

HANSON, J.M., JANNEY J.R. (1975): "Repair Techniques for Concrete Structures", IABSE-FIP-CEB -RILEM-IASS-Colloquium, vol. IV, Liège.

PARK R. (1977): "Members Behaviour as Related for Design Criteria", Sixth World Conference on E.E., New Delhi.

TASSIOS T.P., PLAINIS P. (1977): "Re-design of R.C. Buildings, Damaged by an Earthquake", Atti delle giornate AICAP, Venice.

BERTERO K.V. (1979): "Seismic Behaviour of Structural Concrete Linear Elements (Beams - Colums) and their Connections", CEB, Bulletin n. 131.

Doctor thesis:

THOMPSON, K.J. (1975): "Ductility of Concrete Frames Under Seismic Loading", University of Canterbury, Christchurch, New Zealand.

LEE D. (1976): "Original and Repaired Reinforced Concrete Beam-Column Subassemblages subjected to Earthquake Type Loading", University of Michigan, Ann Arbor, U.S.A.

Specific Reports by members:

MENEGOTTO M., VIA G. (1978): "Considerazioni sul comportamento sismico dei nodi trave-pilastro in c.a. e in c.a.p.", L'Industria Italiana del Cemento.

SAMUELLI FERRETTI A. (1979): "Tests on Reinforced Concrete Members Repaired following Different Techniques after Heavy Damage", AICAP-CEB Symposium, Rome, Italy.

AVRAMIDOU MAIO N. (1981): "Consolidamento sotto vuoto, con impiego di resine, di strutture in cemento armato. Alcuni risultati sperimentali", I° Congresso ASSIRCO, Verona, Italy.

AVRAMIDOU MAIO N. (1982): "Co-ordinate experimental research: general outline", 7 ECEE, Athens, Greece.

VIA G., CIAMPOLI M., LA MESA V. (1982): "Seismic Behaviour of R.C. Beam-Column Subassemblages: First Results of a Co-ordinated Experimental Research on Repair Techniques", 7 ECEE, Athens, Greece.