World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:7, No:6, 2013

Rehabilitation of Reinforced Concrete Columns

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Abstract— In recent years, rehabilitation has been the subject of extensive research due to increased spending on building work and repair of built works. In all cases, it is absolutely essential to carry out methods of strengthening or repair of structural elements, and that following an inspection analysis and methodology of a correct diagnosis. The reinforced concrete columns are important elements in building structures. They support the vertical loads and provide bracing against the horizontal loads. This research about the behavior of reinforced concrete rectangular columns, rehabilitated by concrete liner, confinement FRP fabric, steel liner or cage formed by metal corners. It allows comparing the contributions of different processes used perspective section resistance elements rehabilitated compared to that is not reinforced or repaired. The different results obtained revealed a considerable gain in bearing capacity failure of reinforced sections cladding concrete, metal bracket, steel plates and a slight improvement to the section reinforced with fabric FRP. The use of FRP does not affect the weight of the structures, but the use of different techniques cladding increases the weight of elements rehabilitated and therefore the weight of the building which requires resizing foundations.

Keywords—cladding, Rehabilitation, reinforced concrete columns, confinement, composite materials.

I. Introduction

MONITORING and control structures is identified initial conception errors or realization errors, both changing damage and aging [1] are structured unable to meet the necessary requirements in terms of strength, stiffness and ductility. These anomalies require repair methods or reinforcement which is certainly one of the serious problems currently facing the field of construction. Before engage in the rehabilitation of structures with damage, it is necessary to process a diagnosis to determine the cause.

The choice of the method of repair or reinforcement and materials to implement is defined in terms of the nature and extent of disorder observed taking into account the economic criteria of construction materials and techniques chosen. Products used for rehabilitation must be compatible with the support and present a durability report to the environmental conditions. The benefit of rehabilitation in relation to the demolition and reconstruction is to limit or eliminate operating losses. The main reasons for rehabilitation are: compliance towards the regulations, damage and disorders suffered by materials, changes in functionality and aesthetics. In rehabilitation can be made to proceed:

- a restoration of structural elements with defects that it is desired to mitigate, to obtain a satisfactory aspect as: crack sealing which are mostly due to shrinkage and environmental variations.
- to the strengthening or repair elements insufficiently resistant. Repairs are often conducted in areas where the sections are overstretched and inefficient, but the strengthening against the elements is to improve their mechanical properties so that they provide better solidity both serviceable condition that in ultimate strength. Usually the reinforcing elements are based on an increase of the section of the original support with a section in steel, reinforced concrete or mixed, or confinement by FRP fabric. It is essential that the reinforcement itself is put in charge. This requires knowledge of the transmission of forces between the original support and the new section. In this case it is necessary to be able to evaluate the efficacy of these rehabilitation techniques and evolve the rules of calculation and design of structures towards repairs or reinforcements applied.

II. Rehabilitation of Columns

In the rehabilitation of building structures, it should specify the technical objective covered by the proposed intervention. Three approaches are possible:

- the restoration of the initial bearing capacity of the element to be rehabilitated. This is the repair of the damaged element;
- the increase of the bearing capacity of the element on which we operate, which is generally equivalent to the reinforcement of the damaged element;
- functional replacement of the element with a new element fully ensuring the required bearing capacity, without necessarily removing the element to be rehabilitated;

There are several rehabilitation methods of columns:

- repairing cracks and replacement of damaged concrete and reinforcement;
- concrete cladding: sheaths are applied to the perimeter of the columns or sometimes on one side of the column or more ;
- steel cage: it is to enclose the column in a metal cage formed by four corners of minimum dimensions L50x50x5. They are bonded to each other by flat irons acting as confinement;
- steel liner: It is completely cover the existing column by thin steel sheet. The increase in the dimensions of the column is in the range from 4 to 6mm or more. The void

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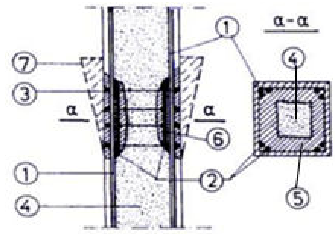
between the sheet and the old surface is completed by a special mortar or concrete.

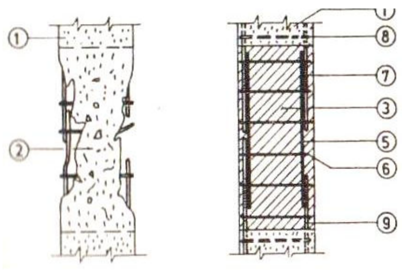
- sandage by FRP fabric: strengthening is done through bonding an FRP fabric, with an epoxy resin on the surface of the concrete [2].

A. Repair Cracks in the Concrete and Damaged Reinforcement

Injections of resin and resin mortar used to repair small cracks are not deep, when the reinforcement is not damaged. In fact appeal to renewals and replacements in case of concrete spelling, buckling of longitudinal reinforcement and openings of frames (Fig. 1).



(a)



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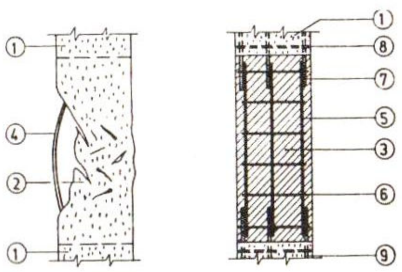

(c)

Fig. 1 Repairing a damaged column [3] (a) Crushing of concrete; (b) Buckling of armatures (c) Open frames
1-Existing sound concrete; 2-Existing damaged concrete; 3-New concrete; 4-Reinforcing outbreak; 5-New rmature; 6-New frames; 7-Welding; 8-Existing frame; 9-Reinforcing existing

B. Concrete Lining

Sheathing is used in case of serious damage or inadequate seismic resistance of the columns according to local existing conditions. The sheaths are applied to the perimeter or on one face or more of the column. The reinforcement sheath is made on site; diameters and quantity of steel are chosen according to the desired resistance and rigidity. The recommended thickness of the sheath is 7cm, in order not to modify the characteristics of the original structure in terms of behavior and / or architectural appearance. In this case you can use a self-compacting concrete. A jacket made of reinforced concrete executed correctly may achieve a higher resistance than the technique of steel profiles. Additional reinforcement should be longitudinal and transverse. At the head of the column, it is necessary to have a physical continuity between the reinforcement and the node (beam-column). So it is recommended to pouring separately the top of support (over 30cm). To ensure the transmission of transverse forces, it is necessary to provide great vigilance executing the connection between the concrete of the jacket and that of the support [4].
The relationship between the total area after liner $\boldsymbol{S}$, the initial section $\boldsymbol{S_e}$ and the section of the liner $\boldsymbol{S_{ch}}$ is given by the following formula (Fig. 2):

$$S = S_e + S_{ch} = (b.h) + 2.(b_1.H + h_1.b) \tag{1}$$

The bearing capacity of the total cross section is:

$$f_{c,d}.S = S_e.f_{c,e} + S_{ch}.f_{c,ch} \tag{2}$$

where:
f_{cd} : required average strength of concrete;
f_{ce} : real concrete resistance of the initial section;
$f_{c,ch}$: concrete strength of lined section.

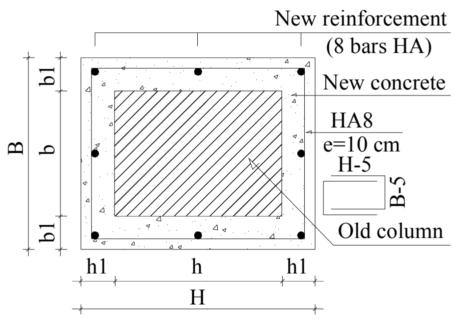

Fig. 2 Lining of column

In the case of poor realization, the real resistance of the concrete is less than the resistance required $\boldsymbol{f_{cd}}$, which requires repair of the damaged element. The strength of the concrete lining is determined from (2) by:

$$f_{c,ch} = \frac{f_{c,d}.S - S_e.f_{c,e}}{S_{ch}} \tag{3}$$

C. Confinement of a Rectangular Column by FRP Fabric

Composite materials based on (FRP) are used for the confinement of concrete for early 1980s. Several studies have been done on the confinement of concrete columns with FRP [5]-[7]. They found that the confined columns show a considerable increase in the compressive strength compared to conventional methods of confinement. When the concrete is subjected to axial compression, it is deformed laterally. This deformation produces a cracking which increases with increasing load and ultimately leads to the rupture of concrete. If the concrete is retained laterally so as to reduce this deformation, the concrete strength and ductility are increased. This phenomenon is commonly called concrete confinement [8]. Confinement can be made either by an external envelope, or by a small spacing between the stirrups. The effect of reinforcement on the ultimate strength at fracture is more important than the original concrete is resistant [9]. The thickness of reinforcement determines the confinement of the element and therefore improves its resistance to axial stress. When the thickness of the reinforcement increases, the resistance to compression of the lined element improves. The thickness of reinforcement is limited as though past certain number of layers of reinforcement, the ductility is affected and so it will be less efficient because they are less able to deform for confining the concrete [10]. For high modulus and low number of layers, beyond a certain length, the negative constraints appear in the circumference of the column, deteriorating the strength properties and leading a quick rupture. These stresses are due to the appearance of microcracks in the top and bottom there or reinforcement suffered the maximum radial stresses. Consider a rectangular column of width ***b*** and a height ***h*** (Fig. 3). Lateral stress of confinement f_l depending on the thickness of the fabric t_{frp} is defined by [11]:

$$f_l = \frac{2\, f_{frp}\, t_{frp}}{\sqrt{h^2 + b^2}} \qquad (4)$$

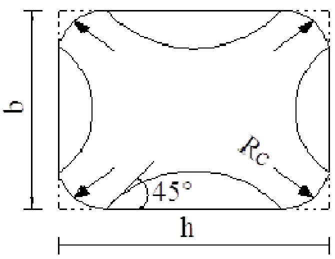

Fig. 3 Action of confinement for rectangular column

The resistance of confined concrete f'_{cc} is given by:

$$f'_{cc} = f_{c,e} + k_1\, k_s\, f_l \qquad (5)$$

Form factors K_1 and K_s are given by:

$$k_1 = 2 \text{ and } k_s = \frac{b}{h}\frac{A_e}{A_c} \qquad (6)$$

$$\frac{A_e}{A_c} = \frac{1 - \left[(b/h)(b - 2R_c)^2 + (h/b)(h - 2R_c)^2\right] / (3A_g) - \rho_{sc}}{1 - \rho_{sc}} \qquad (7)$$

$$\rho_{sc} = \frac{A_l}{b\,h} \qquad (8)$$

$$A_g = b\,h - (4 - \pi) R_c^2 \qquad (9)$$

where:

A_g: Area of all areas delimited by the confinement with FRP;

A_e : The surface of the concrete area which is influenced by the FRP;

A_l : Total area of the longitudinal reinforcement.

In case of repair, we can determine the required thickness of FRP to achieve the required strength f_{cd} from (4):

$$t_{frp} = \frac{f_l \cdot \sqrt{h^2 + b^2}}{2.\, f_{frp}} \qquad (10)$$

The number ***n*** of fabric layers function of a layer thickness ***e*** is given by (Fig. 4):

$$n = \frac{t_{frp}}{e} \qquad (11)$$

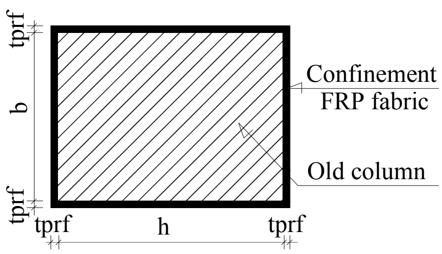

Fig. 4 Confinement by TFC

D. Metal Plates

This technique serves to strengthen reinforced concrete structural elements by attaching metal pieces, which function as armatures [12]. The union of the deck to the structure can be done by: gluing, screwing or anchor. Of viewpoint transmission efforts, the best technique is collage (Fig. 5).

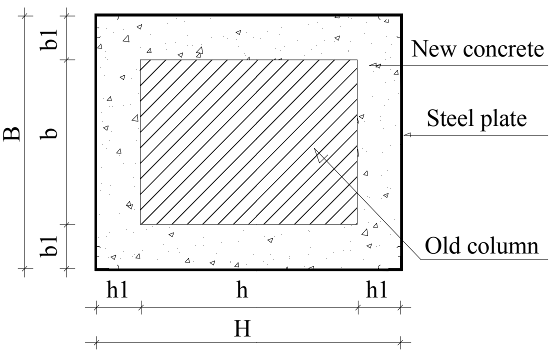

Fig. 5 Confinement by metal plate

E. Metal Corners

In this case the cage is formed of four metal angles of minimum dimensions (50x50x5)mm. They are bonded to each other by connection means acting as a confinement. The advantage of this technique lies in the low dimensional impact caused. The angular profiles do not actually require a substantial thickness. Two factors enhance the efficiency of system: the first, naturally occurring is removing the solder increases imprisonment of the support and the second is the proper expansion of metals (Fig. 6).

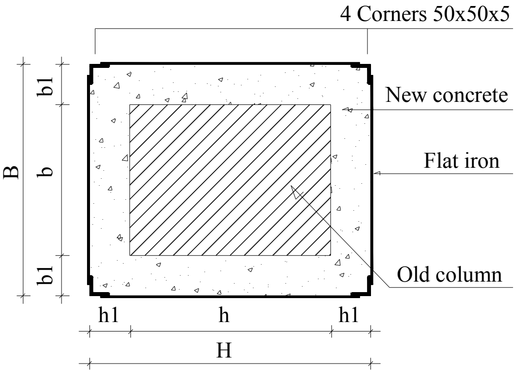

Fig. 6 Reinforcement brackets

III. Study of the Moment-Curvature Relationship

Moments and curvatures are calculated according to the Eurocode 2 [13] integrated into SAP 2000, section Designer [14].

IV. Study of Strengthening of A Reinforced Concrete Rectangular Column

For this study we consider a rectangular column of dimensions *(30x40)cm* initially armed by 8HA16 (Fig. 2), which the resistance of existing concrete *is* $f_{c,e}=25MPa$. For the lining concrete reinforcement, corners and metal plate, the new concrete will be reinforced by *8HA14*.

A. By Concrete Lining

Concrete strength of the lined section is $f_{c,ch}=25MPa$. The values of the curvatures φ_y and moments M_y at the plasticization of steels, of maximum moments M_{max} and corresponding curvatures and φ_u, M_u at rupture and failure mode of the section depending on the thickness of the liner $e_{ch}=b_1=h_1$ are mentioned in Table I and II.

Fig. 9 represents the variation of the moment-curvature of the different reinforced sections. For sections S1 $(e_{ch}=0)$, and $S_2(ech=7cm)$, we see a linear behavior followed by a plastic bearing until failure. From $S_3(e_{ch}=10cm)$ to $S_7(e_{ch}=30cm)$ behavioral differences appear in reports to previous section. The plastic bearing observed in the case of sections S_1 and S_2 is absent for other reinforced sections, this reflects an increase in the rigidity.

The moments at failure are (Table I and II): 9,07 tf.m for S_1; 19,54 for S_2; 21,45 for S_3; 27,53 for S_4 ; 32,25 for S_5; 38,52 for S_6 and 44,15 for S_7. This represents gains compared to the unreinforced section S_1 respectively of: 115%, 136%, 203%, 255%, 325 and 387%.

The curvatures at rupture are respectively of 0,16; 0,14; 0,14; 0,12 and 0,11; while they were 0,26m^{-1} for the section S_1.Increasing the thickness of the concrete liner increases the moment at rupture and reduced the curvature.

TABLE I
Values of Curvatures and Moments for Sections S1, S2, S3, and S4

Section M and φ	S1 e_{ch}=0 (cm)	S2 e_{ch}=7	S3 e_{ch}=10	S4 e_{ch}=15
φ_y (m^{-1})	0,0050	0,0036	0,0031	0,0025
M_y (tf.m)	5,5240	13,0980	14,534	15,5050
Φ_{max} (m^{-1})	0,1667	0,1558	0,0745	0,0791
M_{max} (tf.m)	9,2376	19,5400	22,9610	28,8300
φ_u(m^{-1})	0,2581	0,1558	0,1308	0,1390
M_u(tf.m)	9,0750	19,5440	21,4540	27,5260
Failure mode	C. C.	C. C. followed by P. S.	C. C. followed by P. S.	C. C. followed by P. S.

C. C. : crushing of concrete, P. S. : plasticization steels.

TABLE II
Values of Curvatures and Moments for Sections S5, S6, and S7

Section M and φ	S1 e_{ch}=0 (cm)	S5 e_{ch}=20	S6 e_{ch}=25	S7 e_{ch}=30
φ_y (m^{-1})	0,0050	0,0021	0,0018	0,0016
M_y (tf.m)	5,5240	17,0010	19,2960	21,7190
Φ_{max} (m^{-1})	0,1667	0,0928	0,0888	0,0878
M_{max} (tf.m)	9,2376	35,0305	40,9060	46,3518
φ_u(m^{-1})	0,2581	0,1437	0,1221	0,1079
M_u(tf.m)	9,0750	32,2510	38,5180	44,1510
Failure mode	C. C.	P. S.	P. S.	P. S.

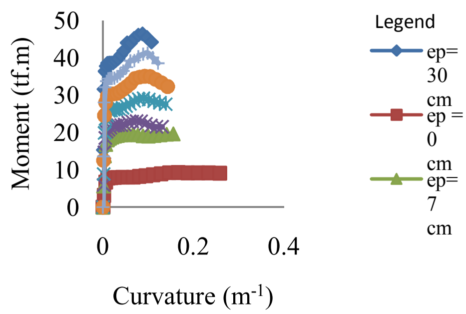

Fig. 9 Moment-curvature diagram for lined concrete sections

B. By FRP Fabric

In this section we study the influence of the reinforcement through the use of carbon fiber fabrics Type STFC, Sika Wrap-230C having a net thickness of 0.13mm for fibers, a nominal resistance tensile strength $f_{frp}=4300MPa$ and an nominal elongation $\varepsilon_{frp}=1,8\%$. The concrete strength $f_{c,e}=25MPa$. The values of various parameters are: $K_1=2$, $b=30cm$, $h=40cm$, $R_c=5cm$, $A_g=1178,50cm^2$; $\rho_{sc}=1,33\%$; $(A_e/A_s)=0,57$; $K_s=0,43$. The concrete strength after reinforcement $f'cc$ is given in Table III.

TABLE III
Concrete Strength after Lining

Thickness t_{prf} (mm)	$f_{c,e}$ (MP)	f_l (MPa)	f'_{cc} (MPa)
0,13 (1 layer)	25,00	3,66	28,15
0,26 (2 layers)	25,00	7,32	31,29
0,39 (3 layers)	25,00	10,98	34,44
0,52 (4 layers)	25,00	14,63	37,58
0,65 (5 layers)	25,00	18,29	40,73
0,78(6 layers)	25,00	21,95	43,88

The values of the curvatures and moments according to the thickness of the fabric t_{prf} are listed on Table IV and V.

TABLE IV
VALUES OF CURVATURES AND MOMENTS OF THE SECTIONS CONFINED BY FRP FABRIC

Section M and φ	S1 e_{ch}=0 mm	S8 e_{frp}=0,13	S9 e_{frp}=0,26	S10 e_{frp}=039
φ_y (m^{-1})	0,0050	0,0049	0,0049	0,0049
M_y (tf.m)	5,5240	5,2000	5,2190	5,2270
Φ_{max} (m^{-1})	0,1667	0,1983	0,1955	0,2198
M_{max} (tf.m)	9,2376	9,3995	9,4566	9,5463
φ_u(m^{-1})	0,2581	0,3070	0,3027	0,3022
M_u(tf.m)	9,0750	8,1310	8,1700	8,1860
Failure mode	C. C.	P. S. followed by C. C.	P. S. followed by C. C.	P. S.

TABLE V
VALUES OF CURVATURES AND MOMENTS OF THE SECTIONS CONFINED BY FRP FABRIC

Section M and φ	S1 e_{ch}=0 mm	S11 e_{frp} =0,52	S12 e_{frp} =0,65	S13 e_{frp} =0,78
φ_y (m^{-1})	0,0050	0,0049	0,0048	0,0048
M_y (tf.m)	5,5240	5,2730	5,2830	5,2910
Φ_{max} (m^{-1})	0,1667	0,2193	0,2189	0,194
M_{max} (tf.m)	9,2376	9,6295	9,7113	9,7657
φ_u(m^{-1})	0,2581	0,3016	0,3010	0,3004
M_u(tf.m)	9,0750	8,2940	8,354	8,4280
Failure mode	C. C.	P. S.	P. S.	P. S.

Fig. 10 shows the variation moment-curvature of the different reinforced sections confined by TFC. From $S_8(e_{prf}=0,13mm)$ to $S13(e_{prf}=0,78mm)$ behavioral differences appear in the reports section unconfined S_1. The plastic bearing observed in the case of the section S_1 is absent for other reinforced sections, this reflects an increase in the rigidity. The moments at failure are: 8,13 tf.m for S_8; 8,17 for S_9; 8,19 for S_{10}; 8,30 for S_{11}; 8,35 for S_{12} and 8,43 for S_{13}.

This represents losses compared at unreinforced section S_1 respectively of: 10%, 10%, 10%, 9%, 8% and 7%.

The curvatures at rupture are respectively of 0,31; 0,30; 0,30; 0,30; 0,30 and 0, 30; while they were 0,26 m^{-1} for the section S_1. The increase in TFC layer decreases the moment to failure and reduces the curvature.

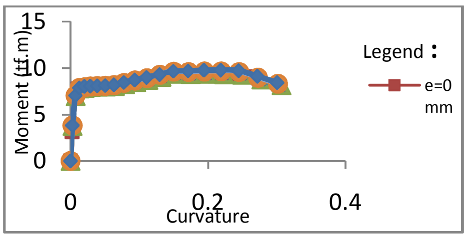

Fig. 10 Moment-curvature

C. By Metal Corners

In this case we use for strengthening a metal corners L50x50x5 whose characteristics are: E_s=200000MPa, f_y=240 MPa. The concrete strength $f_{c,e}$=$f_{c,ch}$=25MPa. The values of curvatures and moments are listed in Table VI. The mode of failure is crushing of concrete followed by plasticization steels. Sections S_1 and S_{14} have a linear behavior followed by a bearing plastic to rupture (Fig. 11). The section S_{14} is more rigid than S_1. The moment is 15,72 tf.m This represents a gain of 73% relative to the unreinforced section S_1. The curvature at rupture is 0,19; whereas it was 0,26 m^{-1} for the section S_1.

TABLE VI
VALUES OF CURVATURES AND MOMENTS OF THE SECTIONS REINFORCED BY CORNERS

M and φ Section	φ_y (m^{-1})	M_y (tf.m)	Φ_{max} (m^{-1})	M_{max} (tf.m)	φ_u (m^{-1})	M_u (tf.m)
S14	0,0032	15,7150	0,1945	24,646	0,1945	24,6460

The moment is 15,72 tf.m This represents a gain of 73% relative to the unreinforced section S_1. The curvature at rupture is 0,19; whereas it was 0,26m^{-1} for the section S_1.

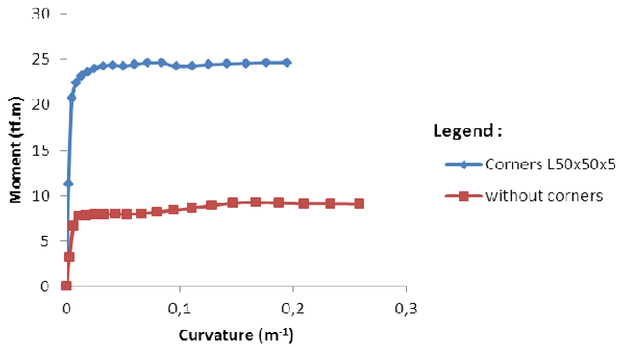

Fig. 11 Moment-curvature diagram of the sections reinforced by corners

D. By Steel Plate

The liner is formed by a metal plate of 2 mm thick bonded to the perimeter of the layer of concrete added. The characteristics are: E_s=200000MPa, f_y=240MPa. The concrete strength $f_{c,e}$=$f_{c,ch}$=25MPa. The values of curvatures and moments are listed in Table VII.

TABLE VII
VALUES OF CURVATURES AND MOMENTS OF THE SECTIONS LINED WITH STEEL PLATES

M and φ Section	φ_y (m^{-1})	M_y (tf.m)	Φ_{max} (m^{-1})	M_{max} (tf.m)	φ_u (m^{-1})	M_u (tf.m)
S14	0,0034	21,4920	0,0285	32,7415	0,1354	30,0710

The mode of failure is crushing of concrete followed by classification steels. The plastic bearing observed in the case of the section $\boldsymbol{S_1}$ is absent for the section S_{15}, which indicates an increase in the rigidity (Fig. 12). The moment is 30,07 tf.m This represents a gain of 231% relative to the unreinforced section S_1. The curvature at rupture is 0,13 whereas it was 0,26 m^{-1} for the section S_1.

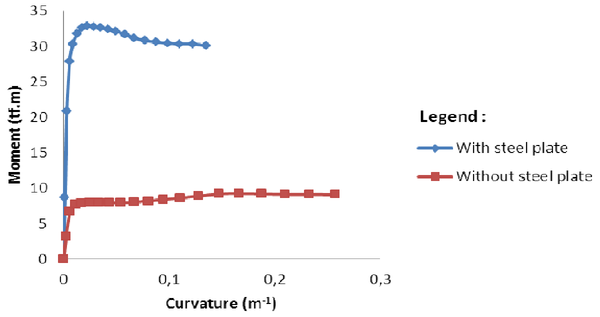

Fig. 12 Moment-curvature diagram of the sections lined with steel plates

E. Comparison of Results

Fig. 13 shows the moment-curvature variation of different reinforcement configurations. The values of moments and curvatures are given in Table VIII.

TABLE
MOMENTS AND CURVATURES OF THE REINFORCED SECTIONS

Section M and φ	S1	S2	S8	S14	S15
	e_{ch}=0 (cm)	e_{ch}=7 cm	e_{frp}=0,13mm	Corners L50x50x5	Metal plate e=2 mm
φ_y (m^{-1})	0,0050	0,0036	0,0049	0,0032	0,0034
M_y (tf.m)	5,5240	13,0980	5,2000	15,7150	21,4920
Φ_{max} (m^{-1})	0,1667	0,1558	0,1983	0,1945	0,0285
M_{max} (tf.m)	9,2376	19,5400	9,3995	24,646	32,7415
φ_u (m^{-1})	0,2581	0,1558	0,3070	0,1945	0,1354
M_u (tf.m)	9,0750	19,5440	8,1310	24,6460	30,0710
Failure mode	C. C.	C. C. followed by P. S.	P. S. followed By C. C.	C. C. followed by P. S.	C. C. followed by P. S.

Sections reinforced by concrete lining its more rigid at rupture compared to other sections. The confinement by TFC retards ruptured of section.

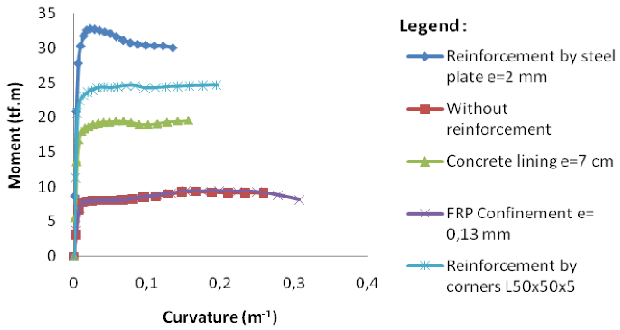

Fig. 13 Comparison of results

IV. CONCLUSION

Various methods of reinforcement increase the rigidity of the reinforced element. The concrete cladding is very effective, the resistance of the element increases with the increase of the thickness of the liner. Beyond 10cm thick, the added weight of the liner increases the weight of the structure, which in certain cases requires resizing of foundations. In the case of reinforcement by TFC, the stress of concrete improves with increasing number of layers of TFC fabric with a slight increase in rigidity. The use of corners and metal plates considerably improves the resistance of the reinforced element. Depending on the resistance, the classifications of the various processes of reinforcement are: the confinement by TFC, concrete lining, the use of corners and metal plates. Strengthening of an element by increasing the section is directly affects the mass of the entire structure, against the use of composite materials can reinforce the elements concerned, without considerable increase which due to their relatively light. The analysis of reinforcement with TFC showed that the cost of the material is greater than that of steel plate, but it is largely compensated by economizing on the time of labor and mobilization of equipment. Composite materials have great flexibility in adapting to more complex geometric forms of reinforcing elements, a lightness compared to steel, handling facilities, transport and on-site implementation and their resistance large enough that other means of reinforcement. These advantages, allows the use of composite materials as a method of strengthening and repair of reinforced concrete structures. The application of TFC an interesting alternative compared to traditional rehabilitation. It is for this reason that the choice of rehabilitation using composite materials is considered favorable.

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