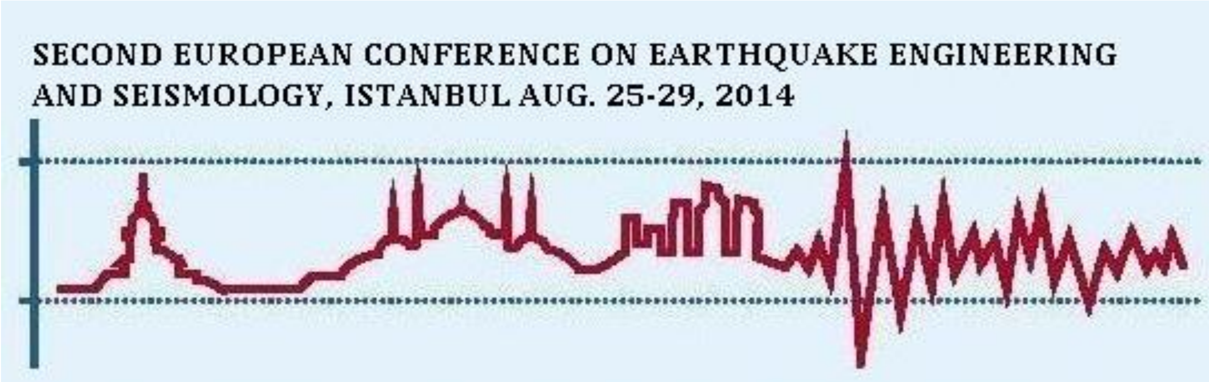

SEISMIC PERFORMANCES OF EXISTING BUILDINGS STRENGTHENED BY REINFORCED CONCRETE JACKETING

Karima DROUNA[1] and Nabil DJEBBAR[2]

Abstract:

In Algeria, more than 80% of existing buildings are not responding to seismic requirements generally, braced by reinforced concrete gantries, system shown weakness under seismic effects when considerations of design and execution were not respected and which without earthquake might remain hidden forever. The famous Boumerdes earthquake 2003, has illustrated this truth.

In this field, this study is the simulation of seismic rehabilitation of existing buildings with poor concrete compressive strength in vertical components, and that by the use of pushover analysis before and after strengthening, where plastic hinges were characterized by a moment-curvature analysis providing sectional capacity of both columns and beams

The analysis conducted on initial structures, shown that the failure mechanism was appearance of soft story caused by concentration of plastic deformations in both extremities of ground floor columns.

Various configurations of structures are tested to determine the effect of several parameters and the failure mechanism was the most found after Boumredes earthquake 2003: soft story

The reinforced concrete jacketing is applied to subject columns where two different jackets were tested: the first one is an ordinary reinforced concrete jacket of 15 cm. and the second one is a self compacting concrete jacket of 07cm to reduce the additional stiffness.

After rehabilitation the retrofit is determined for the two cases and shown clearly that the use of thick jackets could provide an additional rigidity imposed underpinning work and the risk of short periods.

The capacity curves issued using advanced options of SAP nonlinear, Performance points, failure mechanisms, roof displacement. These informations shown the efficacy of concrete jacketing in solving the problem of poor concrete quality but, the thickness of jackets must be reduced to optimize stiffness induced by the intervention that can be the factor imposing the choice of a particular option of seismic rehabilitation.

Introduction:

Many structural mistakes and deficiencies were observed during recent earthquakes over the world: soft stories, short columns, strong beam_ weak column,….etc. caused heavy damages if not

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collapses of multistory reinforced concrete buildings, typically, those braced by beam _column system.

Expertises conducted on damaged buildings in Algeria after the Boumerdes 2003, earthquake have reported a very poor concrete quality with too low compressive concrete strength reason of large collapses.

Since the demolition of a large range of damaged buildings is not obvious, and can cause a very big economic loose, seismic rehabilitation or strengthening is the solution to upgrade these buildings.

The rehabilitation of an existing building is a complicated operation and needs a complete diagnosis to estimate the residual capacity of the structure and to make the appropriate choice of a particular method.

Depending on special needs of each case, buildings initially braced by reinforced concrete gantries should be strengthened by addition of reinforced walls, the use of CFRP, steel casings or reinforced concrete jacketing.

In this field, this contribution is the simulation of seismic rehabilitation of existing buildings with low concrete compressive strength , by the reinforced concrete jacketing applied to initial columns , the choice of such intervention is allowed by first, it’s a widely used solution in Algeria and recommended by the technical control of constructions. Second, the original architectural conception is respected.

Reinforced concrete jacketing:

One of the most commonly used retrofitting technique for strength of existing buildings is jacketing of reinforced concrete columns (E S Julio, F Branco and V D Silva 2003) and can be summarized in:

- Removing concrete from the deteriorated zone.
- Interface surface preparation.
- Use of a bonding agent.
- Application of steel connectors.
- Temporary shoring.
- Anchoring of the added longitudinal reinforcement.
- Continuity between floors of the added longitudinal reinforcement.
- Position of the steel bars of the longitudinal reinforcement.
- Addition of stirrups.
- Addition of new concrete.

Figure 01: reinforced concrete jacketing of columns (BRGM, 2006)

This strengthening method is evaluated using numerical simulation by SAP 2000,where two different jackets are tested 15Cm and 07Cm , as ordinary reinforced concrete jacket and self compacting concrete one respectively.

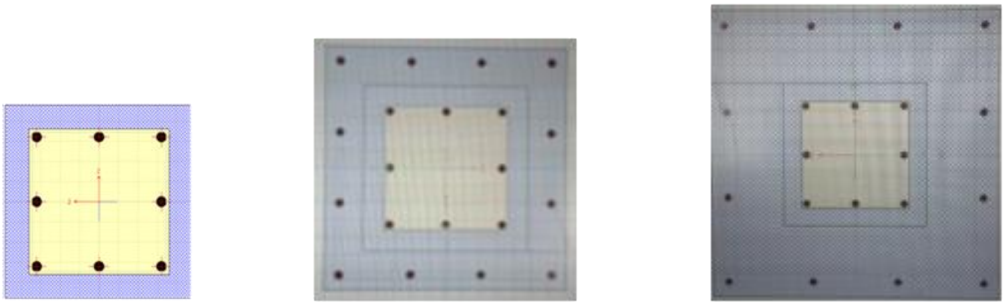


Figure .2 Formwork and reinforcement of columns before and after jacketing

Case study:

A series of RC buildings: 2 to 4 stories with the same typical plan view presented in figure: 01

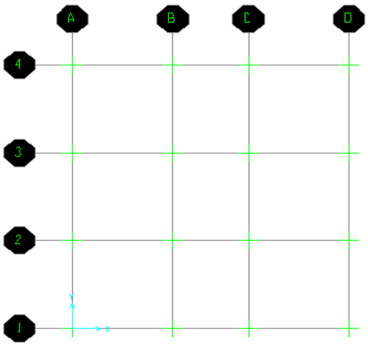


Figure .3 Plan vue of structure

Table 1. Formwork and reinforcement of components

Elément	Dimension (Cm)	As	A's	At
beam	(30 x40)	3 Ø 12	3 Ø 14	Ø8
column	(30 x30)	4 Ø 16 4 Ø 14	/	Ø8

To simulate a more raisonable global behaviour of structures,beams are defined as T sections to take into consideration slab participation in global behavior (A Plumier and H Degee 2010) Columns section is as presented in figure 02, with a confined compressive strenthg calculated using equation: 01 (Mander, Priestley and Park 1984)

$$\frac{f'_{cc}}{f'_{co}} = 2.25\sqrt{1 + 7.94\frac{f'_l}{f'_{co}}} - 2.0\frac{f'_l}{f'_{co}} - 1.25 \quad (1)$$

This range of buildings is studied to represent the most damaged buildings during Boumerdes 2003 earthquake, where the most observed failure mechanism was the soft story as shown in fig: 03

Figure .4 soft story collapses. Boumerdes 2003 . Algeria.

Geometrical characteristics of component and reinforcement were introduced conforming to the Algerian seismic code RPA 99 version 2003, only concrete compressive strength is not as usually recommended (20 – 35 Mpa), a value of 12 Mpa is adopted for all columns.

Modelisation:

A static nonlinear analysis- Pushover- is conducted on subject buildings(Habibullah A,Pyle S 1998) using SAP 2000 V 14.
The nonlinear behaviour of RC elements is introduced by assigning user defined plastic hinges before and after jacketing in both beams, columns extremities.
The plastic hinge length is calculated using equation presented below (Paulay and Priestley 1992)

$$l_p = 0.08l + 0.022 d_b f_y \quad (2)$$

User defined plastic hinge definition:

The sectional capacity is presented by a moment _ curvature analysis, the real curve is idealized by points A,B,C and D meaning first yield, ultimate limite state and collapse so, the branch between first yield and ultimate limite state represented the global nonlinear behaviour tile collapse
The performance levels: immediate occupancy IO, life safety LS and collapse prevention CP are defined as 10%, 60% and 90% of plastic hinge deformation capacity (Inel M, Ozmen H and Bilgin H 2007)

Considering mechanical properties of materials and geometrical characteristic of sections, user defined plastic hinge for an external column is presented in figure 5.

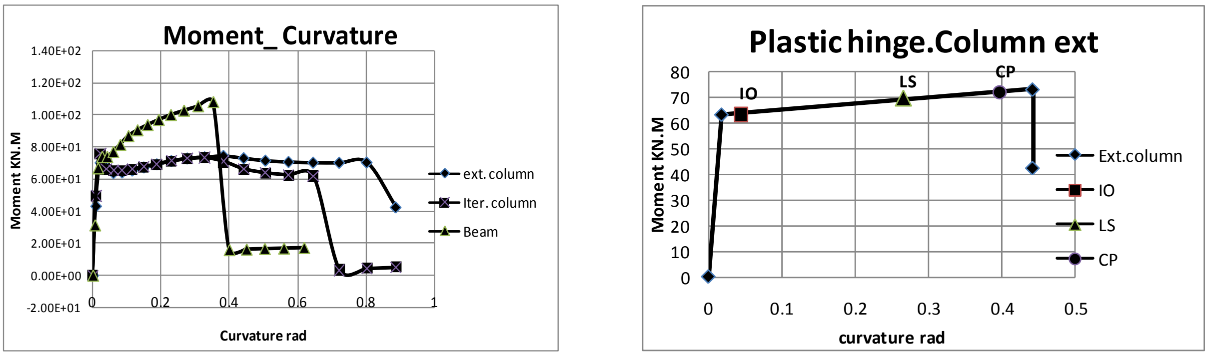


Figure5. Sectional capacity of structural component and definition of user defined plastic hinge

The effect of increase of axial force on M-ø analysis for a central column is presented on figure 6, P 0, P1,P2, P3,P4 and P5 means axial forces on column and for each added story.

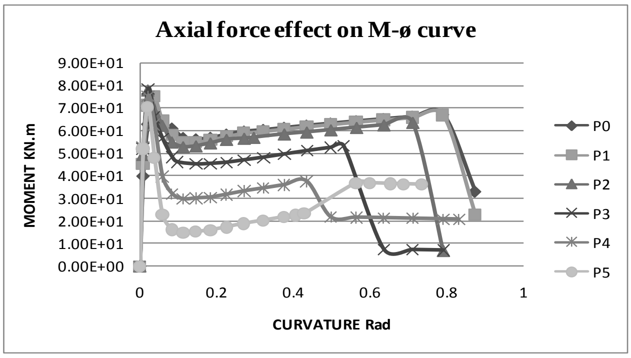


Figure06: axial force effet on Moment- curvature curves

Jacketed columns:

The jacket is assigned as centered box section to the initial columns section as shown in figure 07, the jacketed columns provided a different moment curvature curve

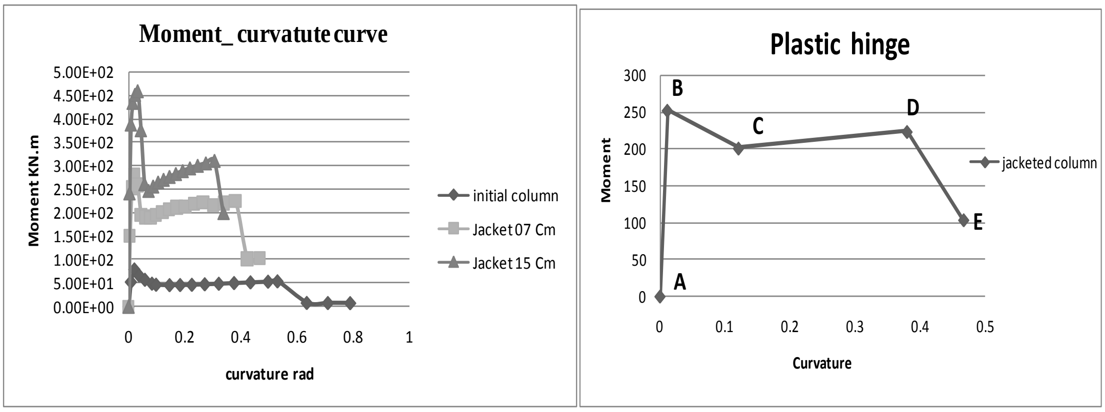


Figure07: sectional capacity and idealization of moment- curvature curve

After intervention, the new user defined plastic hinge adopted by authors, respect the different states of behaviour clearly illustrated on the idealized curve

- First yield point B.
- Plasticisation of concrete cover of the jacket, point C which defined as immediate occupancy for the new plastic hinge.
- Loose of the hole jacket, point D defined as CP for the new plastic hinge .
- A value of 50% of plastic curvature between IO and CP is adopted as the performance level LS is proposed for the new plastic hinge.

Notations: IO, LS and CP are conserved for the new plastic hinge to respect those use in SAP 2000, and wich suggest by several codes (FEMA 356. 2000)
The plastic hinge for jacketed columns is defined as shown in fig: 08

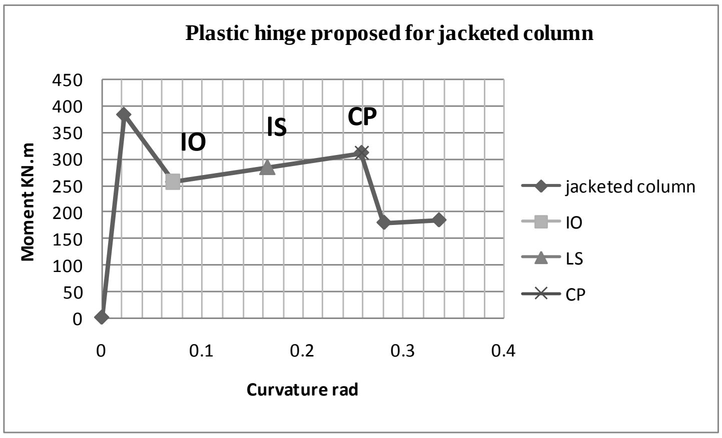


Figure08:Plastic hinge for jacketed column

Intervention effect on initial periods and frequencies:

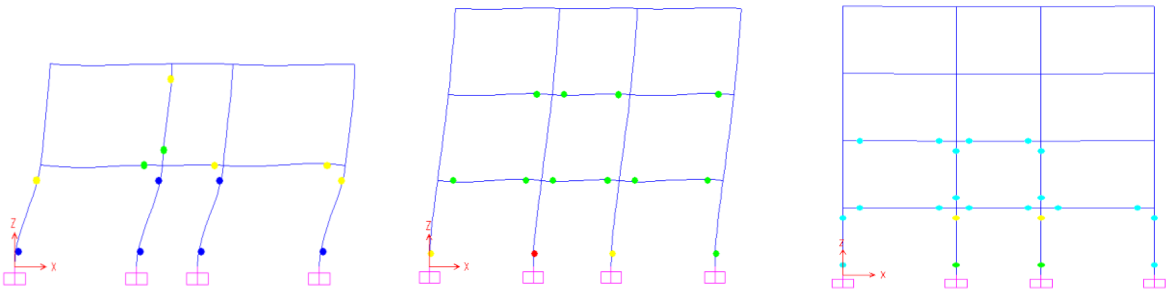
Table 02:Intervention effect on initial periods and frequencies:

	Initial structures		Jacket 07Cm		Jacket 15Cm	
	frequencies	periods	frequencies	periods	frequencies	periods
R+1	0.99	0.73	1.00	0.61	1.32	0.51
R+2	0.89	1.00	1.27	0.78	1.70	0.58
R+3	0.75	1.33	0.98	1.01	1.31	0.76
R+4	0.61	1.63	0.78	1.26	1.04	0.95
R+5	0.52	1.93	0.66	1.50	0.86	1.15

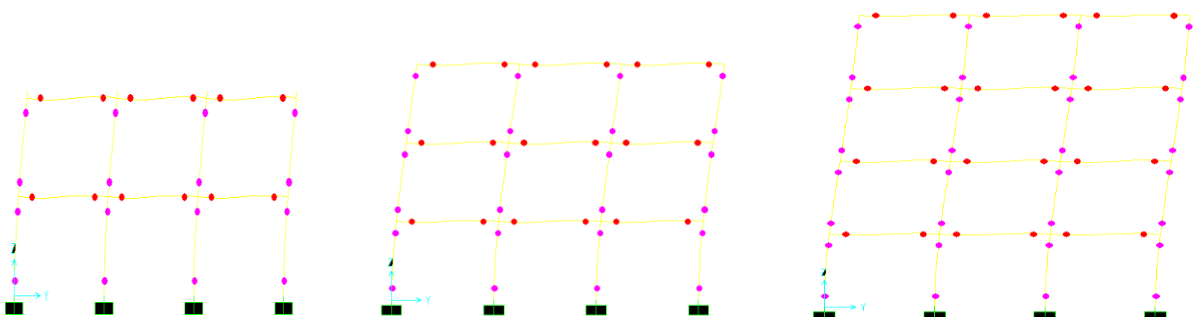
Pushover analysis results:

Failure mechanism:

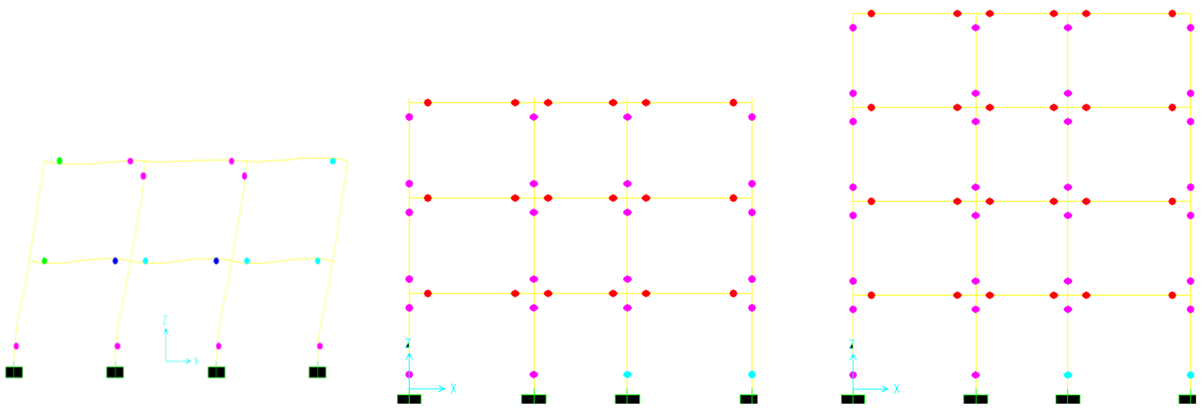
a-Initial structure:



b-Reinforced concrete jackets e= 15 Cm



c- Self compacting concrete jackets e= 07 Cm



Capacity curves:

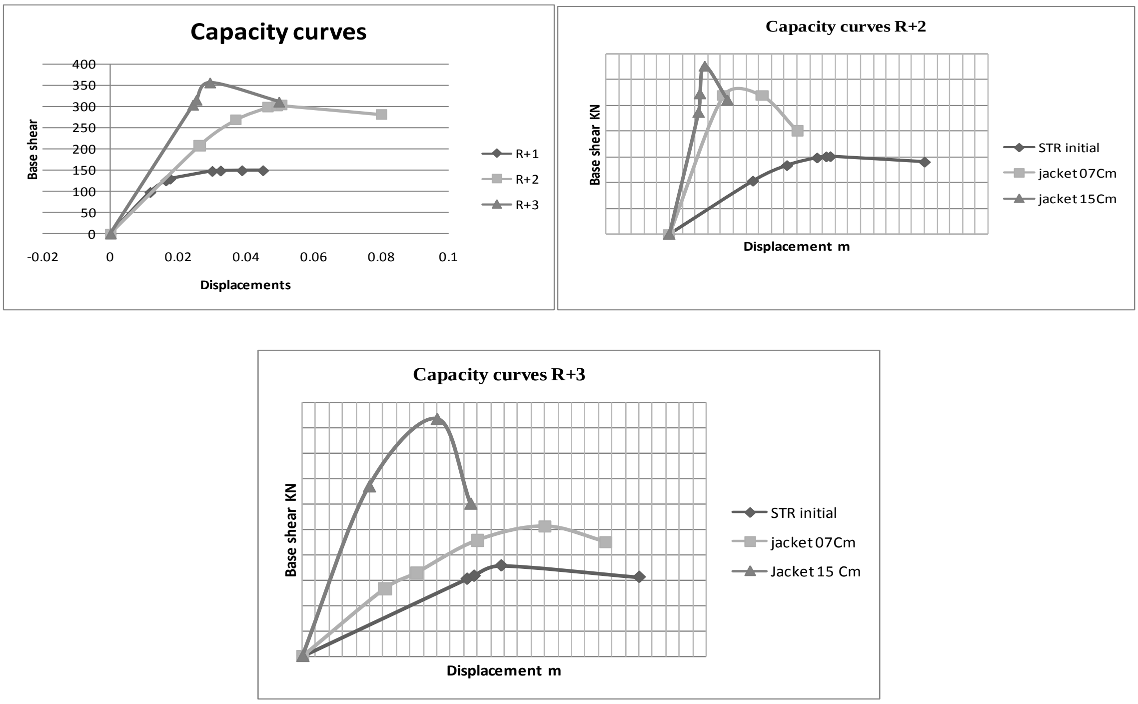


Figure 09: capacity curves presentation

Roof displacement:

Table 03: Roof displacement

	Demand RPA. (m)	Initial str Displ. capacity	$\frac{C_d}{D_d}$	RC jackets Displ. capacity	$\frac{C_d}{D_d}$	SCC jackets Displ. capacity	$\frac{C_d}{D_d}$
R+1	0.06	0 ,04	**0.66**	0.04	**0.66**	0.06	**1**
R+2	0.09	0,07	**0.77**	0 ,052	**0.57**	0.089	**0.98**
R+3	0.12	0,087	**0.72**	0.074	**0.61**	0.102	**0.85**

Base shear:

Base shear demand is calculated according to RPA 99, version 2003 and that by eq: 03

$$V = \frac{A.D.Q}{R}.W \quad (03)$$

Table 03: base shear verification

	Demand R PA. (KN)	Initial str V capacity	$\frac{C_d}{D_d}$	RC jackets V capacity	$\frac{C_d}{D_d}$	SCC jackets V capacity	$\frac{C_d}{D_d}$
R+1	72,03	69,43	**0.96**	125,15	**1.73**	180	**2.50**
R+2	110,97	104,40	**0.94**	375,25	**3.38**	354,30	**3.19**
R+3	150,03	118,14	**0.78**	450,03	**2.99**	387,84	**2.58**

Discussion and comments:

This study shown that the pushover analysis can be applied to estimate the retrofit of the reinforced concrete jacketing, we have to note here that assigning jackets as reinforced boxes has not permitted to consider the confinement effect for the jacket.

For initial studied structures, the energy dissipation is made first, through beams and continue through columns which directly collapsed because they haven't the ability of deformation and we arrive to soft stories formation, or mixed failure mechanism with concentration of plastic deformations in the ground floor.

We record collapse prevention and collapse plastic hinges without arrive to the minimal displacement recommended by our code RPA 99, version 2003 assuming to ensure the life safety level with a roof displacement of 1% of total height of the building.

For jacketed structures, the two variant RC and SCC provide a failure mechanism made by plasticization of beams and we have the first yield of columns only when the total collapse of beams is reached so, the rule of weak beam_ strong column is realized by jacketing.

The base shear demand is quietly satisfy by the intervention and for all case studied but, the most important Remarque is that the global behavior of reinforced structures is elastic not ductile until collapse because applying 15 Cm jackets for all columns for such low tall buildings render the structure very rigid.

For the 07Cm jacketing, this Remarque is not so remarkable and we have formation of IO and LS plastic hinges so, columns participate in global behavior before total collapse of beams.

The additional stiffness hasn't allow the displacement and that by deficiency of ductility, this is very remarkable for the 15Cm jackets.

The axial force increase induced by RC jacketing impose underpinning work to requalify the initial foundations, a simple verification of dimensions after jacketing shown that for thin jackets the additional force can be compensate by the margins of safety of pre-dimensioning but, for the 15 Cm the additional axial force became more significant and in this case foundations also must be strengthened and this can cause supplementary cost can be solved with optimization of jackets thickness.

Conclusion:

The pushover analysis can be a tool to estimate the retrofit of strengthening operations and the global behavior of rehabilitated buildings if true parameters are introduced.

RC jacketing can solve the problem of poor concrete quality but the thickness of jackets must be reduced by the use of self compacting concrete .

We judge that the jacket of 15 Cm widely used in Algeria is not justified and provided very low ductile constructions.

In such case studied of low concrete compressive strength and conforming reinforcement, a reasonable choice of columns to rehabilitate and not for all can reduce the additional stiffness and provide more displacement ability for columns, here we propose that only central columns must be jacketed because they are the vulnerable ones and if the solicitations are not very important (case of external columns) a good confining steel –and it's our case- can compensate the poor compressive strength but, not for the more solicited ones.

Nota:

In this contribution, assigning RC jackets as reinforced boxes did not allow to consider the effect of concrete confinement for the new part of columns sections(jackets).so the retrofit of such intervention, by one hand can be more and this can justify the very low ductility and by the other hand can be a safety margin for probable mistakes in jackets realization.

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