# NONLINEAR BEHAVIOUR OF LIGHTLY REINFORCED CONCRETE STRUCTURAL WALLS IN SEISMIC ZONE

**D. Salima[1] and R. Lassoued[1]**

[1]*Department of Civil Engineering, Faculty of Science and Technology*
*Laboratory of Materials and Durability of Constructions*
*University Constantine 1, Algeria Email: Sali05000@yahoo.fr*

**ABSTRACT:**

The vulnerability of reinforced concrete structures realized in the Seventies 1970 submitted to seismic loadings is one of major preoccupations of researchers, because their designs were based on rules which are not more topicality. The parameters taken into account in this study to idealize the deficiencies of rules are: low rate of reinforcements, type of reinforcement, resistance moderate of concrete. Analysis to test these altered structures with one or the two parameters above mentioned is carried out in the nonlinear domain in optics to analyze their behavior under seismic action. In this work we present a modeling strategy based on finite elements combined with a discretization of wall more solicited by successive thin layers. The estimated performance level achieved during a seismic action is obtained from capacity curves under incrementally increasing loads. Using a pushover analysis, a characteristic non linear force-displacement relationship can be determined. The results of numeric model are confronted with those of Algerian Para seismic Rules (RPA) in force have allowed the determination of profits in terms of displacement, shearing action, ductility. The introduction of confining as a local model makes it possible to refine the numeric model and improves the total behavior of structure. A parametric analysis is concretized to set in obviousness the weakness of structures conceived and carried out in the years 1970.

**KEYWORDS:** Vulnerability, structure analysis, modeling, old building.

## 1. INTRODUCTION

Seismic code of Algeria (RPA-99) permits to reach an acceptable level of security for new structures located in seismic zone. On the other hand the old still building poses an important problem of safety in case of violent earthquake, because these structures were dimensioned according to rules which are not more topicality. For security worry in case of violent earthquake, various researchers in seismic domain studied through different models the estimate of damage of this type of structure. walls can provide the required lateral stiffness and strength for resisting the lateral loads due to earthquakes. Hence, several research as well in theoretical and numerical domain as experimental,were conducted to investigate the behaviour of RC shear walls under the lateral loads in order to enable the designers to predict their seismic response in a building when subjected to a severe ground motion, Schnobrich [1], Fintel and Ghosh [2]; Agrawal and al. [3]; Subiedi 1 [4]; Pauly, T [5]. Their studies showed, in particular, that the cross walls with openings can present a ductile behavior by effectively dissipating the energy induced by earthquake. Several research relates the proposal of two big families of modeling for analysis of the behavior of structures walls .A rigorous modeling by finite elements based on a detailed interpretation of the local behavior , Spacone and al [6] and those of Moulin and al [7],their general principle relates on the integration of the constraints developed in fibers of each section. This model permits to calculate the resultants of the internal efforts in each section. Martinelli and Filipou [8], showed that multifibre modeling is very appropriate to represent the hysteretic behavior of bearing wall of reinforced concrete. It allows, for example, to take account of the change of position of the neutral axis of sections in proportion as they fissure Belmouden Y,Elharif A. [9] based on the Modeling of reinforced concrete load-bearing walls by multi-layer finite elements. Vulcano [10]; Hamsas [11]…ect). Their research relates on a strategy based on the concept of macro-element.

Each macro-element is composed to N uniaxial subelements assembled in parallel and of a nonlinear horizontal spring representing the shearing. The aim of this paper is to present a method able to evaluate the global behavior of a structure from its local behavior of concrete and reinforcement; for concrete we can quote the searches of Mazars J [12], the constitutive model of Kent and Park [13] and Mander et al [14]. And for reinforcement behavior was taken elastic perfectly plastic, we chose the elastoplastic model to reduce the time and the size of calculations in modeling. The parameters taken into account in this study to idealize the deficiencies of rules are: low rate of reinforcements, type of reinforcement, resistance moderate of concrete. Analysis to test these altered structures with one or both parameters above mentioned is carried out in the nonlinear domain in optics to analyze their behavior under seismic action. A section of reinforced concrete can be easily modeled as a stack of several layers of steel and concrete. The multilayer finite element has therefore been selected for this study to be able to assess local damage, combined with a discretization of the most solicited wall by successive thin layers (Miao et al. [15],) hybrid model combining the macros elements and local sections in optics to analysis the influence of the local behavior on total behavior of structure. Following the current advances in earthquake engineering methodologies, nonlinear static pushover analysis is an interesting way in the field of performance based seismic design. A capacity curves derived starting from an incremental analysis from the load permits to locate the point of performance of structure. The results of numeric model are confronted with those of Algerian seismic Rules (RPA) in force have allowed the determination of gains in terms of displacement, shearing action, and ductility. The introduction of confining as a local model makes it possible to refine the numeric model and improves the total behavior of structure. A parametric analysis is concretized to set in obviousness the weakness of structures conceived and carried out in the years 1970.

## 2. BEHAVIOR AND DISCRETIZATION

### 2.1. *Damage Model for Concrete*

Non-linear material models are used for confined and un-confined concrete based on(Mander et al. 1988). [14]. , allows us to effectively simulate the behavior of the confined concrete and unconfined, ordinary or high-strength in compression as in traction. this unified model, rising from the research tasks undertaken by the New Zélandaise school, is characterized by the simplicity of its application and by its cover of all the usual section forms the effective constraint of lateral confining , equal in each direction , was found function of the report/ratio of the compressive strengths of the confined concrete $f'_{cc}$ and unconfined $f'_{co}$ This model is defined by the equations (1 and 2):

$$f_c = \frac{f'_{cc}\, mr}{r - 1 + m^r} \qquad \text{Where} \qquad m = \frac{\varepsilon_c}{\varepsilon_{cc}} \tag{1}$$

and,

$$\frac{f'_{cc}}{f'_{co}} = 2.25\sqrt{1 + 7.94\,\frac{f'_l}{f'_{co}}} - 2.0\,\frac{f'_l}{f'_{co}} - 1.25 \tag{2}$$

The transversal passive pressure of confinement ($f'_l = k_e f_l$) deployed by the transversal reinforcement on the core of concrete, resulting from a triaxial compactness, clearly improves the compressive strength and possibly the ductile behavior. On the basis of this fact, the ultimate longitudinal deflection of compression of the confined concrete will not be reached that by rupture of the transverse reinforcement. The parameter represents the effective coefficient of containment taking account of the effect of arc on the concrete registers between the transverse reinforcement and the longitudinal reinforcement. Resulting from a state of compression triaxial, it clearly improves the compressive strength and possibly the ductile behavior.

Consequently, the ultimate longitudinal deflection of compression of the confined concrete will not be reached that by rupture of the transversal reinforcement.

### 2.2. *Models of Steel*

For reinforcement, the concrete code of Algeria CBA-93 [16] adopts a conventional diagram stress-strain defined by a deformation at the end of elastic phase $\varepsilon_{se} = \sigma s/Es$ and an equal ultimate deformation has 10 ‰ with a constraint in the reinforcements.

### 2.3. *Choice of Adapted Discretization*

The shear wall is modeled using a fine mesh of smeared multi layer shell element is based on the principles of composite material mechanics and it can simulate the coupled in-plane/out-of-plane bending and the coupled in-plane bending –shear nonlinear behaviors of RC shear walls. The shell element is made up of many layers with different thickness. And different material properties are assigned to various layers (figure1) this means that the reinforcement rebars are smeared into one layer or more. During the finite element calculation, the axial strain and curvature of the middle layer can be obtained in one element. Then according to the assumption that plane remains plane, the strains and the curvatures of the other layers can be calculated .and then the corresponding stress will be calculated through the constitutive relations of the material assigned to the layer. From the above principles, it is seen that the structural performance of the shear wall can be directly connected with the material constitutive law. For performance based design, the recommendation of ACI 40 and FEMA 356 define the performance criteria for the flexural RC members in terms of plastic rotations . Therefore for practical engineering further development of this model is needed . in the case of the wall or wall segment behavior is governed by shear , shear drift ratio as the deformation measure can be used as defined in ATC 40.

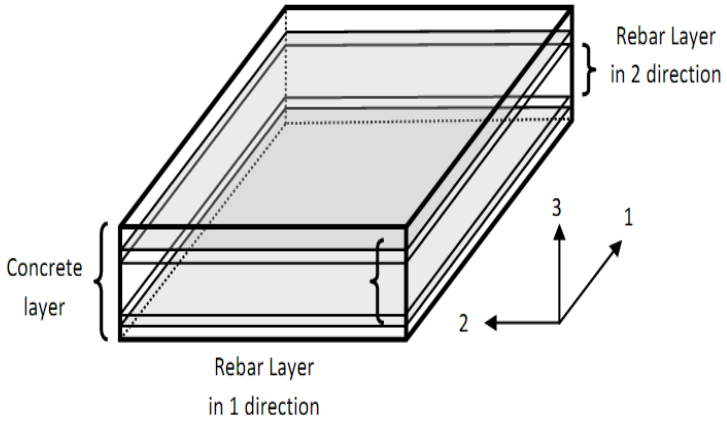


Figure 1. Multi –layer shell elements

## 3. BUILDING DESCRIPTION

Wall structure analyzed composed of seven story, even in plan and in elevation, residential building, implanted in a firm soil, classified according to the RPA99 soil S2, in a average seismicity zone (IIb zone), the story height being of 3.06m and 4.00 m for ground floor The full floor filled the rigid horizontal diaphragm in their plans, our analysis relates to the wall more solicited, The models developed in this study implemented in the Sap 2000 V12 [20] Software, which has general purpose finite **Fig2**: view in plan of structure element codes.

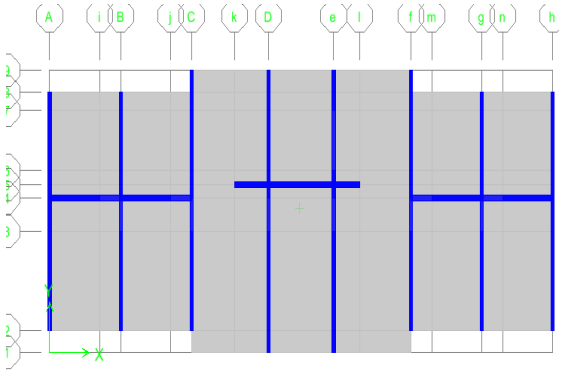


Figure 2. View in plan of structure element codes

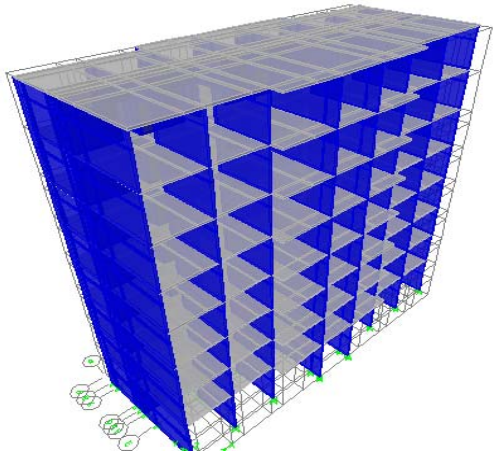

Figure 3. View in 3D of structure

### 3.1. *Characteristic of Materials*

Table 1. Mechanical characteristics of materials

| Materials | Parameters (MPa) | Reference case conform | 1st case | | 2nd case | 4th case |
|---|---|---|---|---|---|---|
| concrete | fc28 | 25 | 12 | 16 | 25 | 12 |
| | fbc | 18.478 | 8.87 | 11.82 | 18.478 | 8.87 |
| | Ec | 32164 | 25183.7 | 27718.3 | 32164 | 25183.7 |
| | fc | 2.1 | 1.32 | 1.56 | 2.1 | 1.32 |
| STEEL | E0 | 2.105 | 2.105 | 2.105 | 2.105 | 2.105 |
| | fsty | 400 | 400 | 400 | 215 | 215 |

## 4. RESULTS AND DISCUSSION

### *4.1. Structural Analysis*

The parameters of our analysis related primarily to a low resistance of the concrete (concrete with resistance equal 12 and 16 MPa), the second case relates to a slightly reinforcement structural, a third case: structure reinforced with smooth bars and the last case will be analyzed with the two above mentioned parameters. For the checking of structure resistance, the evaluation was carried to the shearing action at the base of structure noted $V_{base}$ compared with those imposed by the RPA [21], is given by the following formula:

$$V_{RPA} = \frac{A.D.Q}{R} W \tag{3}$$

The Values obtained by capacity curve furnish by push over analysis, The monitoring of ductility of certain preselected critical zones of a structure is one of the most important observations to be made during nonlinear analysis defined by the factor of ductility of displacement $u_D$, often employed in seismic calculation. Is also defined as the report of maximum horizontal displacement δu of a definite structural level , on displacement δy corresponds to the yield stress:

$$u_D = \frac{\delta_U}{\delta_Y} \tag{4}$$

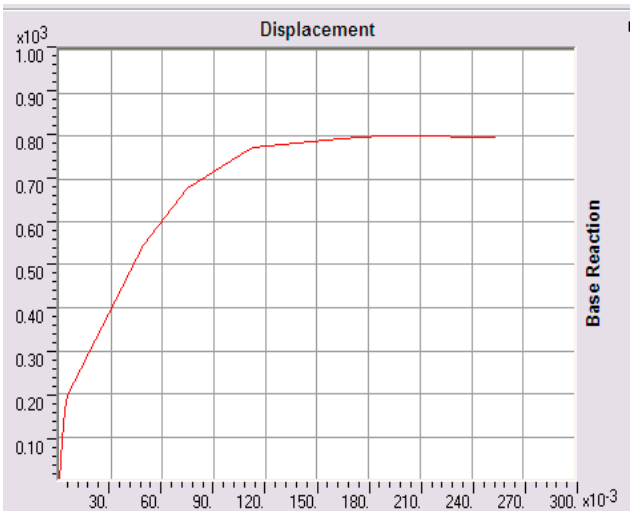


Figure 4. Capacity curve of reference case where the Resistance of concrete is equal to 25MPa (conform to the RPA)

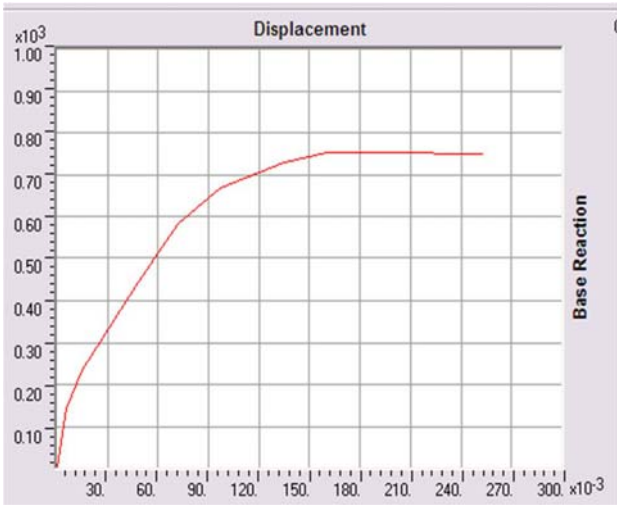


Figure 5. Capacity curve of 1[first]case where the Resistance of concrete is equal to16MPa

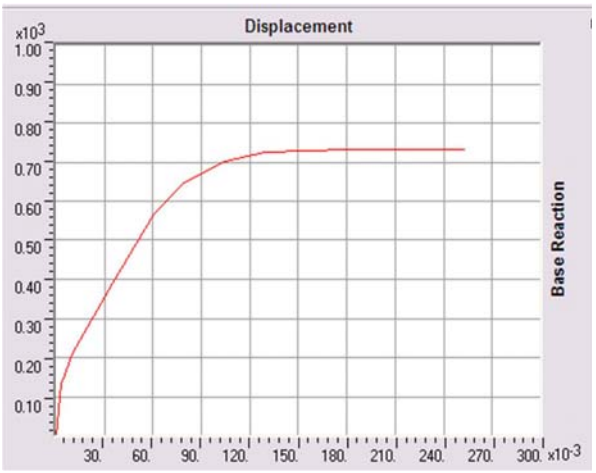


Figure 6. Capacity curve of 1firstcase where the Resistance of concrete is equal to12MPa

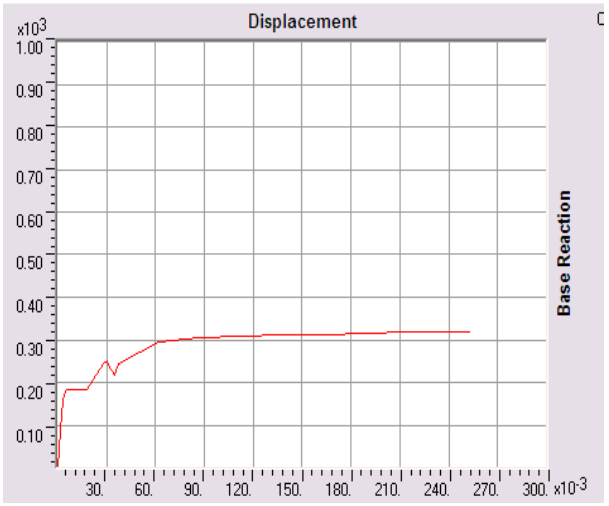


Figure 7. Capacity curve of 2[nd] case where the structure is reinforced with a minimal section and concrete resistance is equal to 25 MPa

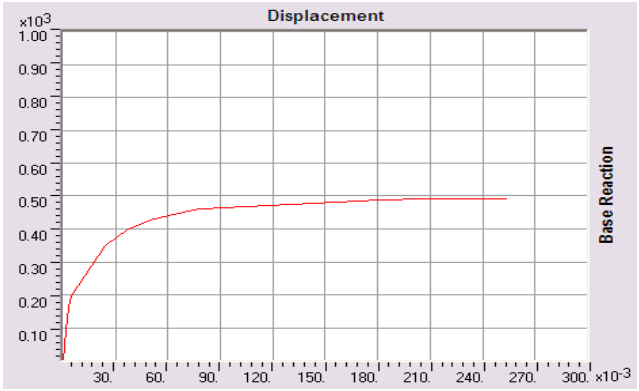


Figure 8**.** Capacity curve of 3rd case where the structure is reinforced with smooth bars and Concrete resistance is equal to 25 MPa

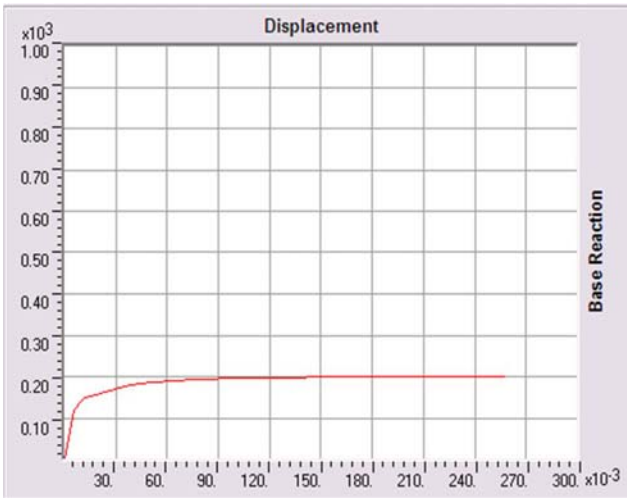


Figure 9. Capacity curve of 4th case where concrete resistance is equal to12 MPa and the structure is reinforced with smooth bars

Table 2. Evaluation of the capacity-demand ratio in term of resistance and ductility

| | $\frac{V_{base}}{V_{RPA}}$ | $u_D$ |
|---|---|---|
| **reference case where the Resistance of concrete is equal to 25MPa (conform to the RPA)** | **1.89** | **3.7** |
| **( concrete of 16 MPa)** | **1.78** | **3.03** |
| **( concrete of 12MPa)** | **1.70** | **2.28** |
| **Cas du béton faiblement armé** | **0.74** | **2.18** |
| **Concrete reinforced with smooth bars** | **1.14** | **2.96** |
| **concrete of 12 MPa and structure is reinforced with smooth bars** | **0.47** | **1.3** |

***Comment 1***

It can be seen from the capacity curves and the results of Table 2 that: About the rapport $V_{BASE}$ /$V_{RPA}$ , we remarks that when this report higher to 1, this is implies that the capacity of structure is clearly higher of the request. and we record in this case a gain of resistance and consequently the ruin risk by lack of resistance is not considered. Whereas for other cases (Case of the slightly reinforced concrete and concrete with 12 MPa and reinforced with smoothes bars) that wants to say that the structure is menaced (there is a danger on the level of building and life safety). In ductility term we will be able to retain the following observations: Ductility in displacement can be influenced by:

- **Resistance of the concrete**, concrete with low resistance (concrete of 12 and 16 MPa) is a little more ductile than concrete of 25 MPa.
- **Rate of reinforcement:** By comparing the reference case with those from the case of concrete reinforced with a minimal section, the structure behavior seems to be affected by rate of reinforcement; the increase in this parameter increases the ductility in displacement.
- **Type of reinforcement**: following the reference case our analysis put in evidence that the ductility in displacement decreases by using the smooth bars as reinforcement.

The lightly reinforced structural or having a resistance of concrete in compression according to the case of analysis, proved vulnerable and must be comforted.

**a) Effect of confinement of concrete**

After having done our analysis for different above mentioned cases, we introduce the confinement of concrete to improve the performance of structures, the results are tabulated below

Table 2. the influence of confining concrete on the resistance and ductility

| | **Reference case** | **1st case** | **2nd cas** | **3rd cas** | **4th cas** |
|---|---|---|---|---|---|
| **fcy** | **25** | **12** | **25** | **25** | **12** |
| **fy** | **400** | **400** | **400** | **215** | **215** |
| **fcc** | **36.73** | **18.98** | **25.87** | **25.67** | **12.86** |
| **εcu (10-3)** | **67.6** | **62.1** | **28.5** | **35.1** | **7.72** |

***Comment 2***

The introduction of confinement by using transverse steels increases the resistance and the deformation of concrete. This increase is due to the resistance offered by these steels against the lateral swelling of concrete. When the longitudinal constraint of a confining specimen with transverse steels increases, the lateral pressure exerted by these steels also increases

In fact, these steels have a passive role; it means that for low longitudinal stresses, there is no swelling of concrete, so there is no lateral pressure. For the high values of this constraint, the swelling of concrete exerts a pressure on transverse steels, The reaction of the latter is a lateral pressure on the concrete. This phenomenon continues until atteidre the maximum resistance. In this case the confined concrete has a plastic balance between longitudinal and lateral constraints.

- The introduction of confinement as local model helps to refine the numerical model and improves the overall behavior of the structure.

## 5. GENERAL CONCLUSION

The principal objective of this study is to show the nonlinear Behavior of lightly reinforced concrete structural walls in seismic zone, following conclusions were derived as a result of the study performed in this paper:
The Post elastic characteristics of materials have influence with a dominant manner on the behavior of the structure elements in the plastic domain
The introduction of confining as a local model makes it possible to refine the numeric model and improves the total behavior of structure.
A multi-layer enough fine modeling, we allowed to have a cartography which reflects the state of stress in any point of wall
Calculation in the nonlinear domain, we permitted to have various gain in terms of displacement, resistance and ductility
The lightly reinforced structural or having a resistance of concrete in compression according to the case of analysis, proved vulnerable and must be comforted.

## REFERENCES BIBLIOGRAPHIQUES

[1]Schnobrich, W.C. 1977. Behaviour of RC structures predicted by finite element method. Computers and Structures, 7 : 365 -376.

[2] Fintel, M., et Ghosh, S.K. 1974. Application of inelastic response history analysis in the aseismic design of a 31-storey frame-wall building. Earthquake Engineering and Structural Dynamics, 2 : 325 -342. -2943.

[3] Agrawal, A.B., Jaeger, L.G., et Mufti, A.A. 1981. response of RC shear wall under ground motions. american Society of Civil Engineers Journal of structural Division, 107 : 395 -41 1

[4] Subeidi, N.K. 1991. RC coupled shear wall structures. 11. Ultimate strength calculations. American Society of Civil Engineers Journal of Structural Engineering, 117 : 681 -698.

[5] Paulay, T. 1986. The design of ductile RIC structural walls for earthquake resistance. Earthquake Spectra: the Professional Journal of the Earthquake Engineering Research Institute, 2 :783 -823.

[6] Spacone, E., Filippou, F. C., & Taucer, F. F. (1996). Fibre beam-column model for the non-linear analysis of r/c frames : part I, formulation. Earthquake Engineering & Structural Dynamics, 25(7), 711-725.

[7] Moulin, S., Davenne, L., & Gatuingt, F. (2003). *Élément de poutre multifibre (droite)*: Fascicule R3.08 - Document Code Aster.

[8] Martinelli, P., & Filippou, F. C. (2009). Simulation of the shaking table test of a seven-story shear wall building. *Earthquake Engineering & Structural Dynamics, 38*(5), 587-607.

[9] Belmouden Y., Elharif A. " Modélisation des murs porteurs en béton armé par éléments finis multicouches ", Revue Européenne des Eléments finis (REEF), Vol. 12, pp. 907-932, Editions Lavoisier, Août, 2003.

[10] Vulcano, A., Bertero, V.V. and V Coloti ,1988 «Analyical modeling of RC structural walls , proceeding, 9 th word conference on Earthquake Engineering 6, Tokyo-kyoto

[11] Modélisation par macro-éléments du comportement non-linéaire des ouvrages à voiles porteurs en béton armé. These pour obtenir le grade de docteur Présentée par Miloud Hemsas,Université de BORDEAUX1

[12] Mazars J**.,** Application de la mécanique de l'endommagement au comportement non linéaire et à la rupture du béton de structure. Thèse de doctorat d'État, Université Paris VI, 1984.

[13] **K**ent, D. C., & Park, R. (1971). Flexural member with confined concrete. Journal of Structural Division, Proceedings of the American Society of Civil Engineers, 97(7), 1969-1990.

[14] Mander, J. B., Priestley, M. J. N, Park, R. «Theoretical stress-strain model for confined concrete», *Journal of Structural engineering*, 1988, Vol.114, No 8, pp. 1804-1825.

[15] Miao ZW, Lu XZ, Jiang JJ and Ye LP (2006). Nonlinear FE Model for RC Shear Walls Based on Multi-layer Shell Element and Microplane Constitutive Model, Computational Methods in Engineering And **Science,** EPMESC X, Aug. 21-23, 2006, Sanya, Hainan,China.

[16] CBA-93, 1994. Algerian concrete Code 1993. Technical rules document DTR-BC National center of Applied research in Paraseismic Genius (CGS), Algiers .

[17] Applied Technology Council (1996). ATC-40-seismic Evaluation and Retrofit of Concrete buildings, Redwood City, California.

[18] FEMA 356 (2000). Pre-standard and commentary for the seismic rehabilitation of buildings, american society of Civil Engineers, Reston, Virginia.

[19] CSI (2009). SAP2000: Static and Dynamic Finite Element Analysis of Structures 14.0, Computers and Structures, Inc., Berkeley, California.

[20] RPA99 (2003), " Algerian Paraseismic rules, Version 2003 ",regular technical Document, DTR B C 2 48, paraseismic National center of applied research engénie, Algiers.