SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

ANALYSIS OF CONFINEMENT EFFECT ON STRENGTH AND DUCTILITY IN REINFORCED CONCRETE STRUCTURES

Amar KASSOUL [1] , Abdelkader BOUGARA [2] and Halima ABDESSELAM [3]

ABSTRACT

The lateral confinement in reinforced concrete structural components is an essential parameter to allow designer to use a sufficient percentage of transverse reinforcement in order to ensure the required strength and ductility for the structure. This paper deals mainly with the influence of lateral confinement on strength and ductility in reinforced concrete structures designed according to Algerian standards. An overview of the non-linear static analysis method is described below to better understand this analysis. Two different representative structures designed according to Algerian code for the design of earthquake resistant buildings (RPA99/v2003) are identified for the purpose of this study. This analysis provides the capacity curves for each structure with regard to the compressive strength and the volume percentage of the transverse reinforcement. The results obtained show that the lateral confinement improves widely the strength and the local ductility of the structure elements, although their effect on the overall behavior of the structure remains limited.

INTRODUCTION

The resisting frames are currently very used in reinforced concrete structures in the world. It is known that the behavior of these bracing is an important factor that determines the performance of the entire structure against seismic action. Indeed, the prediction of transverse reinforcement in the potential plastic hinge regions of columns and beams requires special importance.

Several studies have been conducted on the importance of confinement in improving the strength and ductility of cross sections and linear elements (Mander et *al.*, (1988), Paultre and Légeron, 2008). However, its effect regarding the whole structure was not really highlighted and illustrated according to many authors (Kadid and Boumrkik (2008), Poluraju and Rao (2011), Kumar et *al.* (2012)). Algerian earthquake resistant code (RPA99/v2003, 2004) has achieved an acceptable level of safety for structures located in seismic zones, although this code is still missing an explicit model for the confinement of linear reinforced concrete elements.

The present work deals mainly with lateral confinement and its influence on the strength and the ductility of the entire reinforced concrete structures dimensioned according to current Standards Algerians. To highlight this effect, two resisting frames structures of five and seven levels are considered in this work (Abdesselam, 2013). The design of the structures has been performed according to Algerian earthquake resistant code (RPA99/v2003, 2004) and Algerian Concrete Code (CBA 93, 1994).

[1] Laboratory of Structures, Geotechnics and Risks (LSGR), UHB Chlef, Algeria, amkassoul@hotmail.com

[2] Laboratory of Structures, Geotechnics and Risks (LSGR), UHB Chlef, Algeria, aekbougara@hotmail.com

[3] Laboratory of Structures, Geotechnics and Risks (LSGR), UHB Chlef, Algeria, abdhalima@hotmail.fr

The nonlinear behavior of the two structures will be emphasized with regard to the lateral confinement of the sections. In addition, a non-linear static analysis is performed to determine the curves capacity of these structures.

PUSHOVER ANALYSIS METHODOLOGY

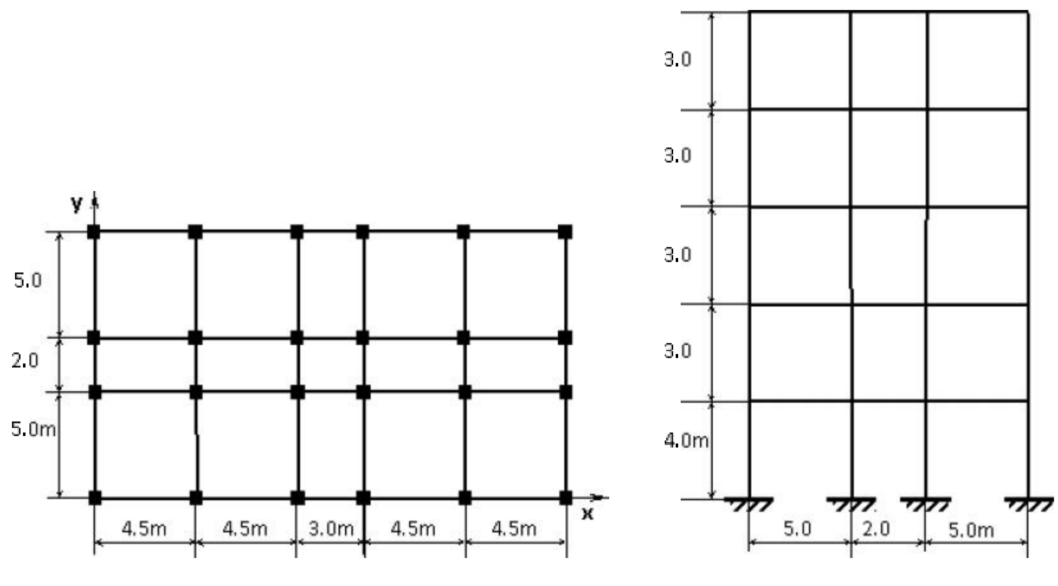
The non-linear static method or pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral forces, representing the inertial forces which would be experienced by the structure when subjected to ground motion. Under incrementally increasing loads various structural elements may yield sequentially. As result,, the structure experiences a loss in stiffness at each event., The characteristic nonlinear force-displacement relationship is determined by using the pushover analysis and any force and displacement can be chosen. The first pushover load case is typically used to apply gravity load. aThen, subsequent lateral pushover load cases are specified to start from the final conditions of the gravity (Kadid and Boumrkik (2008), FEMA 440, 2005).

The non-linear static procedure stated in EC8 (Eurocode 8, 2005). It requires development of the pushover curve by applying first gravity loads, and then followed by monotonical increasing lateral forces with a specified height-wise distribution. This method is relatively simple and provides information about strength, displacement, ductility and display mode of plastic hinges. This enables the identification of the critical elements, which may reach the limit states during an earthquake. Non-linear static (pushover) analysis provides the curve capacity of the structure, which represents the horizontal effort at the base for the building according to the displacement of the later.

DESCRIPTION OF THE STRUCTURES

In the present study, two resisting frames structures of five and seven levels are considered in order to analyze the effect of lateral confinement on reinforced concrete structures (Abdesselam, 2013).. The design of these two structures has been performed according to Algerian earthquake resistant code (RPA99/v2003, 2004) and Algerian Concrete Code (CBA 93, 1994).

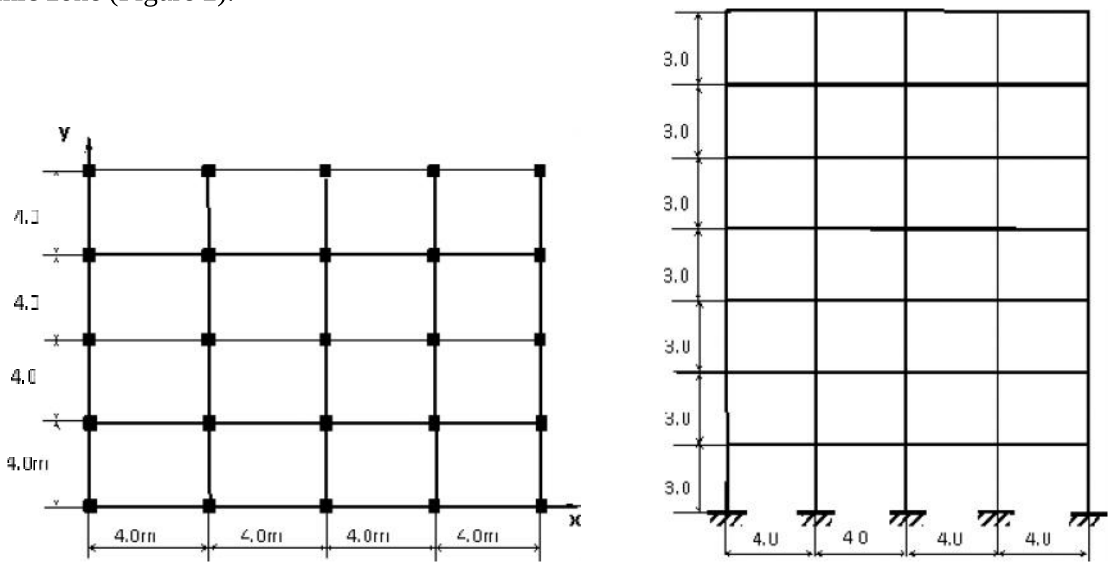
The first structure is a building with five levels (N5), located in a region characterized by average seismic zone. The plan views and elevation of the first structure are shown in Figure 1.



a. Seen in plan view **b.** Seen in elevation

Figure **1.** Detail and data structure (N5)

The second building is composed of seven levels (N7), located in a region known as low seismic zone (Figure 2).



a. Seen in plan view **b.** Seen in elevation

Figure **2.** Detail and data structure (N7)

RESULTS AND DISCUSSIONS

The effect of the confinement on the strength and ductility for these structures is studied by considering two important parameters, namely the concrete compressive strength f_c and the volumetric ratio of confining reinforcement ρ_{vt}. The stress-strain model for confined concrete of Mander (Mander et al., 1988) is applied in this investigation.

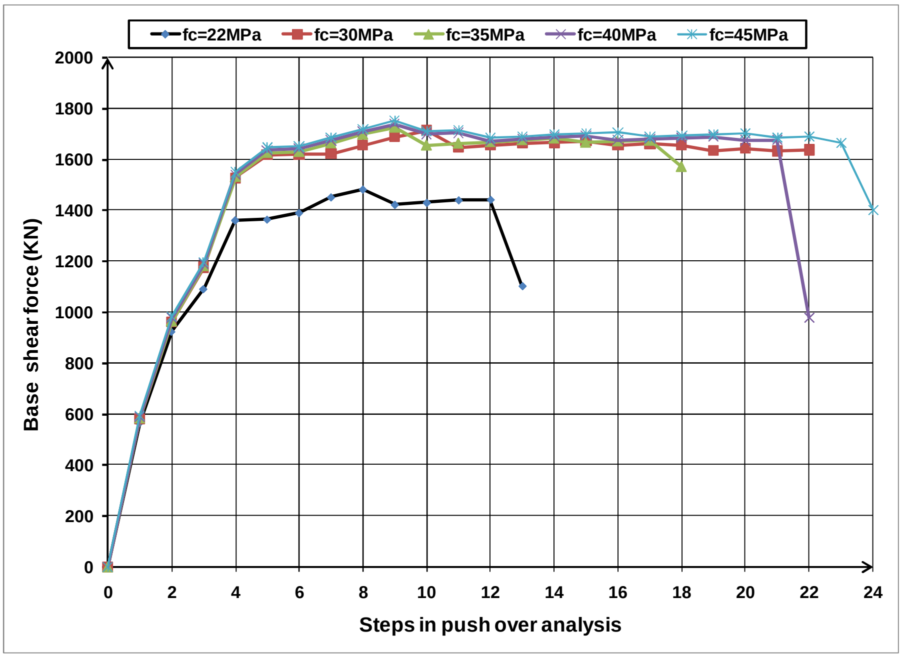
EFFECT OF COMPRESSIVE STRENGTH ON STRENGTH AND DUCTILITY

The purpose of this section is to investigate the nonlinear behavior of the two identified structures. This non-linear behavior is expressed in terms of strength, rigidity and ductility in presence of the confinement. The results obtained using SAP2000/v14.2 software (CSI Manual, 2009) are analyzed and interpreted for five values of the concrete compressive strength (f_c); namely, 22 MPa, 30 MPa, 35 MPa, 40 MPa and 45 MPa. In general, the different curves capacity are characterized by a linear phase elastic followed by a non-linear phase corresponding to the formation of flexural and shear hinges, since the elements of the structure beyond the yield point begin to be plasticized up to the ruin.

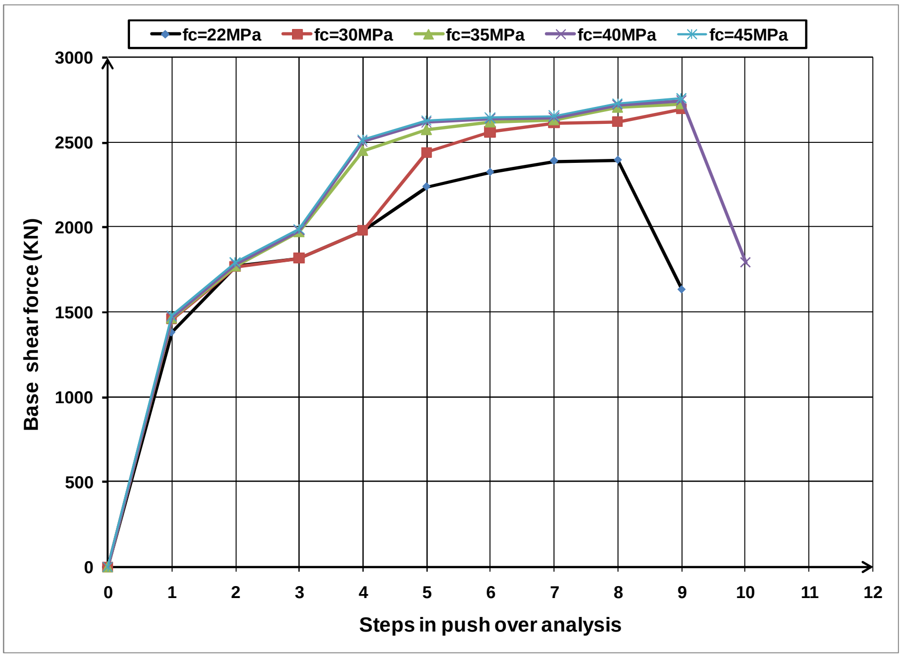
Figure 3 (a) includes five capacity curves, corresponding to each value of f_c for the structure (N5). These curves represent the development of the shear effort at the base of the building versus displacement. According to this figure, we can observe that once the value of f_c exceeds 22 MPa, these curves overlap with each other, and the effect of increasing f_c becomes less significant on the ability of the structure (N5). Similar observations for N7 structure are shown in Figure 3 (b). As a result, the increase in f_c has a minor effect on the whole improvement of the resistance of the structures.

Table 1 gives comparison between the maximum shear values and the curves corresponding to the compressive strength values (fc) ranging from 22 MPa to 45 MPa. The values shown in Table 1 give an ultimate capacity of 1451 KN to the structure with fc equal to 22 MPa. This value increases up to 1749 KN, when the structure is confined with 45 MPa, about an increase of 17% in resistance. This indicates clearly the positive contribution of increasing the compressive strength for N5 structure. Same observation is found for N7 structure in this table.

Various values of the global ductility factor μ_Δ are presented in Table 1. This later clearly indicates an increase of the ductility factor from 4.68 to 6.22 corresponding with 22 to 45 MPa respectively in N5 structure. Thus, it is to be noted that the ductility factor μ_Δ increases proportionally with the increase of f_c. Similar findings were found for N7 structure. This shows a considerable increase in global ductility, exceeding 50% for both structures, which provides a significant ductility to the structure.



a- N5



b- N7

Figure 3. Comparison of curves capacity for five values of f_c

Table 1. Stiffness and ductility for both N5 and N7 structure at five values of f_c

	N5 structure				N7 structure			
fc (MPa)	**22**	**30**	**40**	**45**	**22**	**30**	**40**	**45**
Efforts at the elastic limit V_y (KN)	1244	1531	1558	1570	2055	2249	2293	2315
Shear force intersection αV_y (KN)	933	1148	1168	1177	1541	1687	1720	1736
maximum effort V_u (KN)	1451	1712	1738	1749	2393	2706	2743	2758
V_u/V_{base}	1	1,18	1,2	1,21	1	1,13	1,15	1,15
maximum displacement d_u (mm)	239	296	297	297	328	324	324	324
displacement d_y (mm)	51	53	49	48	61	45	42	41
elastic stiffness K (KN/m)	24390	29030	31690	32860	33810	49850	54700	56720
plastic stiffness r.K (KN/m)	1100	744	728	720	1266	1636	1593	1562
global ductility factor μ_Δ	**4.682**	**5.606**	**6.031**	**6.223**	**5.400**	**7.176**	**7.728**	**7.938**

Regarding to the stiffness, Table 1 shows that the elastic stiffness increases widely with the increase of fc for both N5 and N7 structures. Furthermore, the plastic stiffness decreases relatively with the elastic stiffness, which decreases from 1100 to 720 kN/m, corresponding with 30 to 45 MPa respectively. This demonstrates the negative effect of the increase of compressive strength f_c on the plastic stiffness. From these results, we may confirm that the elastic stiffness increases proportionally with the increase of f_c, however, the plastic stiffness shows a clear loss.

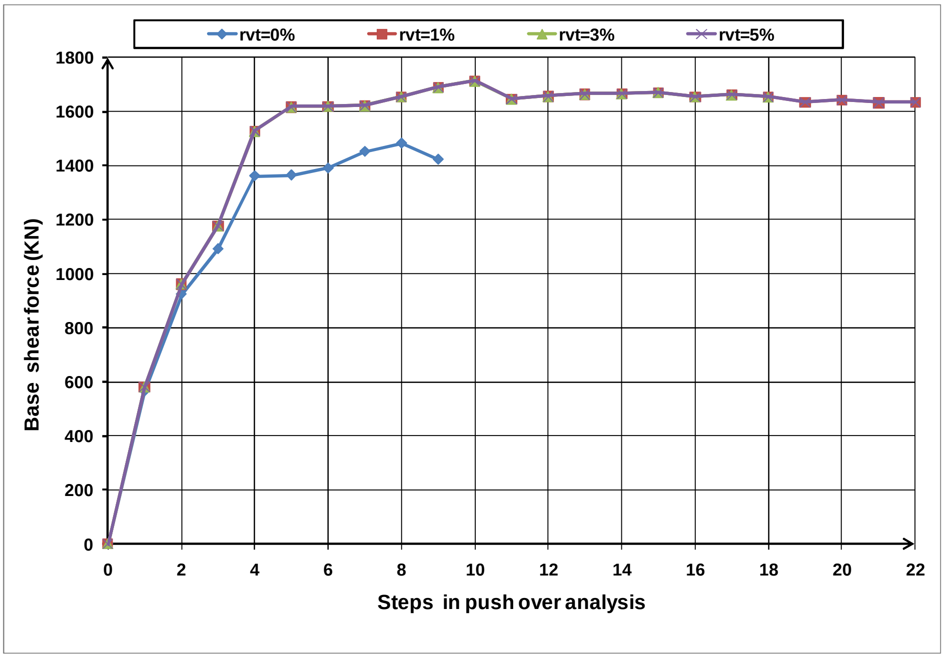
EFFECT OF VOLUMETRIC RATIO OF CONFINING REINFORCEMENT ρ_{vt}

In this section, an attempt to show the effect of confinement on the strength and ductility of structures is made, depending on the volumetric ratio of confining reinforcement ρ_{vt}. In this context, the two identified structures above will be analyzed at four values of ρ_{vt}, namely 0%, 1%, 3% and 5%.

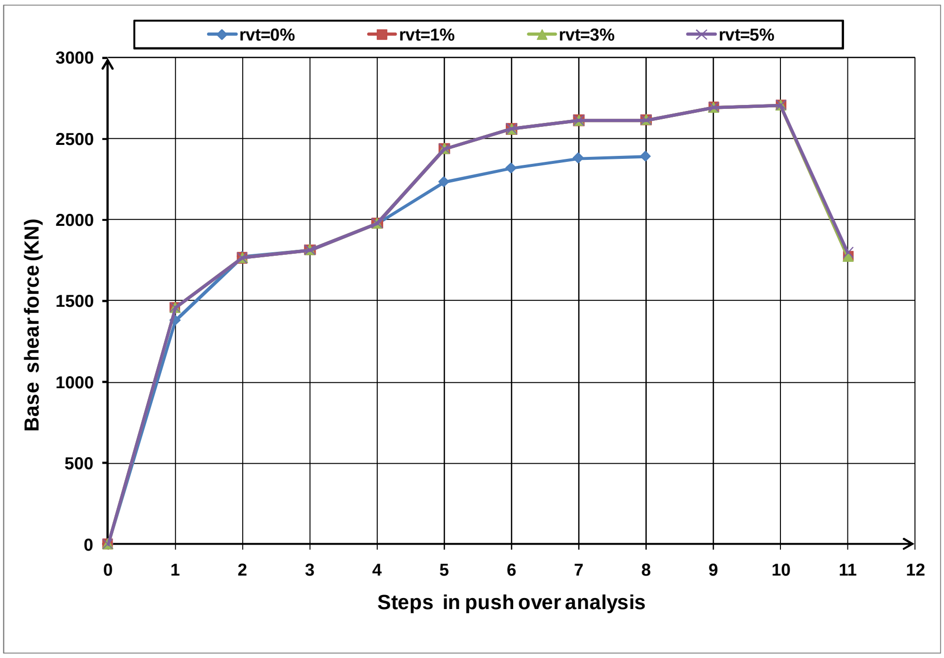
Figure 4 shows the effect of the volumetric ratio of the transverse reinforcement ρ_{vt}, on the behavior of the two structures identified previously. Figure 4(a) illustrates the capacity curves of N5 structure as a function of ρ_{vt}. According to this figure, it is thought that the curve of overall resistance of N5 structure improves with the first increase of ρ_{vt} from 0% to 1%. Furthermore, the increase of ρ_{vt} from 1% to 5% does not provide any improvement of the resistance. Figure 4(b) shows similar observations regarding the effect of ρ_{vt} on the strength for N7 structure. Figure 4 shows the coincidence between the curves corresponding to medium and high confinement values in elastic and plastic areas and far beyond the curve corresponding to the unconfined structure (ρ_{vt} = 0). From numerical point of view, maximum shear force values in Table 2 give an ultimate capacity of 1451 KN in the unconfined structure. This value increases up to 1712 KN when the structure is confined, about an increase of 15%. This illustrates the positive contribution of the confinement elements of N5 structure. Similar findings are shown for N7 structure.

The ductility factors obtained from Figure 4 are presented in Table 2. According to this table, the overall ductility factor μ_Δ is 4.6 for unconfined (ρ_{vt} = 0%) section. When ρ_{vt} increases 1%, μ increases 5.6. It is thought that the overall ductility remains constant when ρ_{vt} slightly increases from 1% to 5%. As a result, the overall ductility factors found show that the effect of increasing the overall ρ_{vt} is minimal, unlike to the local ductility, where the percentage ρ_{vt} improves largely the latter according to many authors (Mander et *al.*, 1988, Paultre and Légeron, 2008).

Table 2 summarizes the different values of the assessed stiffness. This table shows that the elastic stiffness is equal to 24.39 10^3 KN/m and 29.03 10^3 KN/m for unconfined structure (ρ_{vt} = 0%) and confined structure at (ρ_{vt} = 1%) respectively. This elastic stiffness remains constant with the increase of ρ_{vt}.This shows that increasing ρ_{vt} beyond 1% does not affect the elastic stiffness. Regarding the plastic stiffness, there is still a drop despite the increase of ρ_{vt}, which is still observed even when increasing ρ_{vt} up to 5%.



a- N5



b- N7

Figure 4. Comparison of curves capacity for four values of ρ_{vt}

Table 2. Stiffness and ductility of both N5 and N7 structures for four values of ρ_{vt}

-	N5 structure				N7 structure			
°$_{vt}$	**0%**	**1%**	**3%**	**5%**	**0%**	**1%**	**3%**	**5%**
Efforts at the elastic limit V_y (KN)	1244	1531	1531	1531	2055	2249	2249	2249
Shear force intersection αV_y (KN)	933	1148	1148	1148	1541	1687	1687	1687
maximum effort V_u (KN)	1451	1712	1712	1712	2392	2706	2706	2706
V_u/V_{base}	1,00	1,18	1,18	1,18	1,00	1,13	1,13	1,13
maximum displacement d_u (mm)	239	296	296	296	328	324	324	324
displacement d_y (mm)	51	53	53	53	61	45	45	45
elastic stiffness K (KN/m)	24390	29030	29030	29030	33740	49850	49850	49850
plastic stiffness r.K (KN/m)	1100	7440	7440	7440	1261	1636	1636	1636
global ductility factor μ_Δ	**4.682**	**5.606**	**5.606**	**5.606**	**5.376**	**7.176**	**7.176**	**7.176**

CONCLUSIONS

The following conclusions are based on of the lateral confinement of the two structures designed according to Algerians codes (CBA-93 and RPA-99/2003):

- The increase of the concrete compressive strength f_c allows a slight increase in the resistance capacity of the structures
- The global ductility factor of the structure μ_Δ increases proportionally to the increase of the compressive strength f_c
- The elastic stiffness increases proportionally to the increase of the compressive strength f_c. However, the stiffness plastic shows a clear loss and sometimes a decrease with the increase of f_c.
- The capacity curve of the structure improves with the first increase of the volume percentage of the transverse reinforcement ρ_{vt} from 0% to 1%. Beyond this percentage of confinement, no improvement in resistance is observed even at 5%.
- The increase of ρ_{vt} has a minimal effect on the overall ductility, unlike the local ductility, where the percentage ρ_{vt} improves largely the latter.

In general, the parameters influencing the confinement improve significantly the strength and the ductility of the local sections and the structural elements, although this positive contribution is not widely observed in the strength and ductility from the global view of the structure.

REFERENCES

Abdesselam H. (2013), Effet du confinement latéral sur la résistance et la ductilité des structures en béton arme dimensionnées selon le règlement parasismique algérien RPA99/V2003, Mémoire de magister, Université Hassiba Ben Bouali De Chlef, Algeria.

CBA-93 (1994), Code de béton algérien 1993. Document technique réglementaire DTR-BC -CGS, Alger,

CSI Manual SAP2000 V14.1 (2009), Analysis manual: Inelastic Time History Analysis, Computer and Structure Inc.

Eurocode 8, EN 1998-1:2004. Design of Structures for Earthquake Resistance. Part 1: General Rules, Seismic Actions and Rules for Buildings. CEN, European Committee for Standardisation

FEMA 440 (2005), Improvement of Nonlinear Static Seismic Analysis Procedures, Applied Technology Council (ATC-55 Project), p. 392.

Kadid A., Boumkik A. (2008), pushover analysis of reinforced concrete frame structures, *Asian Journal of Civil Engineering (Building and Housing) Vol. 9, 75-83.*

Mander J. B., Priestley M. J. N., and Park R. (1988), Theoretical stress-strain model for confined concrete, *J. Struct. Eng., Vol. 114, No. 8, pp. 1804-1826.*

Naresh Kumar B. G., Avinash Gornale, Abdullah Mubashir (*2012*), Seismic Performance Evaluation of R c-Framed Buildings – An Approach To Torsionally Asymmetric Buildings, *IOSR Journal of Engineering (IOSRJEN), Volume 2, 01-12.*

Paultre P. and Légeron F., (2008), Confinement Reinforcement Design for Reinforced Concrete Columns, *Journal of Structural Engineering, 738-749.*

Poluraju P., Nageswara Rao P. V. S. (2011), Pushover analysis of reinforced concrete frame structure using SAP 2000, *International Journal of Earth Sciences and Engineering , Volume 04, No 06 SPL, pp. 684-690.*

RPA-99/V2003 (2004). Règles parasismiques Algériennes 1999. Document technique réglementaire DTR-BC 248 – Centre National de Recherche Appliquée en Génie sismique (CGS), Alger, P.171.

Soni Priya K., T. Durgabhavani, K. Mounika, M.Nageswari, P.Poluraju (2012), Non-Linear Pushover Analysis of Flatslab Building by using SAP2000, *International Journal of Recent Technology and Engineering (IJRTE), Volume-1, 29-33.*