EARTHQUAKE RESPONSE OF RC COUPLED SHEAR WALLS STRENGTHENED WITH COMPOSITE SHEETS WITH VARYING WIDTHWISE MATERIAL PROPERTIES: CREEP AND SHRINKAGE EFFECT

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ABSTRACT:

This paper investigates the effect of creep and shrinkage of reinforced concrete (RC) coupled shear wall structures strengthened by bonded composite sheets, having a sinusoidal distribution of fibers, on the seismic analysis. A finite element model for lateral stiffness is presented. In the numerical formulation, the adherents and the adhesives are all modeled as coupled shear wall elements, using the mixed finite element method. A numerical results are presented that relate to the performance of RC coupled shear walls bonded with composite sheets with varying widthwise material properties under several different earthquake scenarios in Algeria (El-Asnam and Boumerdes). The influence of creep and shrinkage effect relative to the time of the casting, and the time of the loading of the shear walls is taken into account. Numerical results from the present analysis are presented to illustrate the time-dependent effects on the earthquake response.

KEYWORDS: Earthquake, RC coupled shear walls strengthened, composite sheets, creep-shrinkage, finite element method, time-dependent behavior.

1. INTRODUCTION

In medium to high-rise buildings, reinforced concrete (RC) walls systems are commonly used to resist lateral forces induced by earthquake and wind. The development of simple as well as accurate methods of these plane structural elements has been the objective of many investigators. From a technological point of view, the strengthening of RC shear walls structure has been accomplished by adopting standard materials, mainly cement, concrete and steel. In the past, new reinforcement approaches are rising, they are based on the idea that the strengthening should be light and removable.

Thus, one promising technique to improve the overall strength of RC coupled shear walls structures and to reduce their seismic vulnerability is to retrofit the RC coupled shear walls structures using fibers reinforced plastic (FRP). Moreover, composite materials are characterized by high strength, good durability and lower installation and maintenance cost.

Extensive studies (Shen et al 2003 and Benyoucef et al 2006) have shown that externally bonded carbon fiber reinforced polymer (CFRP) laminates are particularly suited for improving the short-term behavior of deficient RC beams and slabs. A few researches on efficient analyses and experimental studies of the strengthening of RC shear wall structures have been undertaken (Balsamo et al 2005; Meftah et al 2007 and Yeghnem et al 2009).

An important issue in this study is the time-dependent analysis of seismic behavior of RC shear walls strengthened with composite plates having variable fibre volume fraction.

2. FINITE ELEMENT FOR ANALYSIS OF SHEAR WALLS

Theoretically, the finite element method (FEM) has been popular for many years to analyze any type of building structures. However, due to relatively low efficiency and high computing cost, it has never been popular for shear walls analysis.

Cheung (1978) and Kwan (1993) provided a 12 DOFs plane stress element having two translational DOFs and one DOF per node. Their works have been used in many researches. As suggested by Kwan (1993), by neglecting the lateral strain in the wall, which are generally of little significance. The DOFs can be reduced from 12 to 8.

3. THEORY AND SOLUTION PROCEDURE

3.1. Creep and Shrinkage Effect on the Elastic Deformation of RC Shear Wall

Assuming that creep and shrinkage are independent, the shrinkage strain $\varepsilon_b^F(y)$ is given as (Eurocode 2 1991):

$$\varepsilon_b^F(y) = \varepsilon_{sb}(t - t_{bc}) = \alpha T_b \tag{1}$$

Where α, T_b and $\varepsilon_{sb}(t - t_{bc})$ are: a linear coefficient of thermal expansion, the temperature distribution and the shrinkage strain respectively. From (1), it is shown that the shrinkage strain $\varepsilon_b^F(y)$ is related to thermal expansion. This is due to the evaporation of moisture in the hardened cement paste.

The strain $\varepsilon_b(y)$ in the RC shear wall can be expressed as:

$$\varepsilon_b(y) = \varepsilon(y) + \alpha T_b \tag{2}$$

Where $\varepsilon(y)$ is the vertical strain of RC shear walls which is expressed as:

$$\varepsilon(y) = \frac{dv}{dy} \tag{3}$$

We note that in the above equations $E_b = E_b(t)$ and $G_b = G_b(t)$ are the time dependent tangent modulus of elasticity and the shear modulus of the RC shear walls respectively, given as (Trost et al 1970):

$$E_b(t) = \frac{E_{b1}}{1+\chi\varphi(t,t_b)} \text{ and } G_b(t) = \frac{E_b(t)}{2(1+\upsilon)} \tag{4}$$

Where E_{b1} is the tangent modulus of elasticity of the shear wall at time t_{b1}; χ is an aging coefficient depending on strain development with time; and $t_b = t_{b1} - t_{bc}$ (t_{bc} is time of casting of shear wall and t_{b1} time at initial loading of shear wall); $\varphi(t,t_b)$ is the creep coefficient related to the elastic deformation at t_b days.

3.2. Fibre Volume Fraction V_f

The plates are made of fibre composite with varying fibre volume fraction widthwise (Kubiak 2005). Widthwise variable of fibre volume fraction V_f was assumed as sinusoid function in the following way:

$$V_f = Vf_{av} + A_i.cos\left(\frac{2\pi x}{b}\right) \tag{5}$$

Where $Vf_{av} = 0.5$ is the assumed average value for fibre volume fraction, A_i is the sinusoid amplitude defining variation of material properties widthwise plate, with a calculated range of amplitude from - 0.4 to 0.4 and b is width of the plate.

Using Eq. (6) it is possible to determine an equivalent value for the following material properties:

– Modulus of elasticity in transverse direction E_y,

– Shear modulus G_{xy},

– Poisson ratio υ_{xy}.

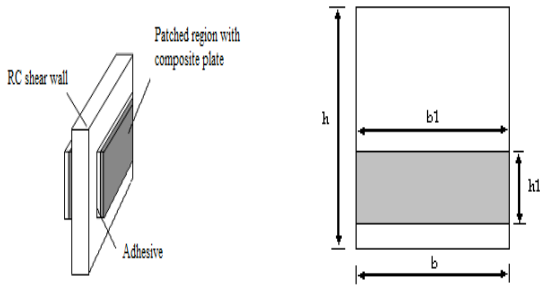
$$E_y = E_m.\frac{E_m.\left(1-\sqrt{V_f}\right)+E_f.\sqrt{V_f}}{E_m.\left[1-\sqrt{V_f}.\left(1-\sqrt{V_f}\right)\right]+E_f.\sqrt{V_f}.\left(1-\sqrt{V_f}\right)}$$

$$G_{xy} = G_m.\frac{G_m\sqrt{V_f}\left(1-\sqrt{V_f}\right)+G_f.\left[1-\sqrt{V_f}\left(1-\sqrt{V_f}\right)\right]}{G_m.\sqrt{V_f}+G_f.\left(1-\sqrt{V_f}\right)} \tag{6}$$

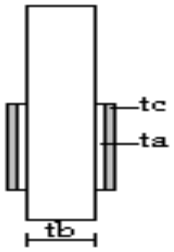
$$\upsilon_{xy} = \upsilon_m.\left(1-\sqrt{V_f}\right)+\upsilon_f.\sqrt{V_f}$$

3.3. Stiffness Matrix of the Shear Wall Element

Figure 1 describe a combination of composite plates having variable fibre volume fraction widthwise and a reinforced shear wall, attached to the two sides using adhesive plates.



(a) (b)



(c)

Figure 1. A strengthened RC shear wall: (a) perspective view; (b) front view and (c) lateral view

The strain energy for each wall element can be written as:

$$U^e = U_B^e + U_S^e \tag{7}$$

Where: U_B^e and U_S^e are the strain energy due to the bending and shear effects respectively, which are written as a function of the strains on the shear wall element.

The strain energy considering only the bending effect U_B^e is done as:

$$U_B^e = \frac{1}{2}\sum_{i=1}^{3}\int E_y^{(i)}(\varepsilon_b(y))^2\,dx\,dy\,dz \tag{8}$$

The expression of the strain energy which relate to the shear effect may be written as:

$$U_S^e = \frac{1}{2}\sum_{i=1}^{3}\int G_{xy}^{(i)}(\gamma(xy))^2\,dx\,dy\,dz \tag{9}$$

The following form of the strain energy for each wall element is expressed by:

$$U^e = \frac{1}{2}d_e^T K_w d_e \tag{10}$$

Where the nodal displacement vector is given as $d_e^T = \{u_1, \omega_1, v_1, v_2, u_2, \omega_2, v_3, v_4\}$. To carry out numerical analysis, we employ the standard finite element formulation to determine the stiffness matrix K_w of a strengthened shear wall element.

3.4. System Equation of Motion

The generalized differential equation of motion for the coupled shear walls may be expressed as:

$$[M]\ddot{D}(t)+[C]\dot{D}(t)+[K]D(t)=-[M]E\ddot{D}_g(t) \tag{11}$$

In which [C] and [K] are the global damping and stiffness matrices of the structures, respectively, $D(t), \dot{D}(t)$ and $\ddot{D}(t)$ are the relative displacement, velocity and acceleration vectors to the structures with respect to base ; E is a location vector which defines the location of effective seismic loads and $\ddot{D}_g(t)$ is the horizontal ground acceleration.

The damping matrix of the model is assumed to be proportional to the stiffness and mass matrices by the Rayleigh's proportionality factors α_1 , α_2 and can be written as :

$$[C]=\alpha_1[M]+\alpha_2[K] \tag{12}$$

The proportionality factors α_1 , α_2 can be obtained from:

$$\alpha_1 = \xi \frac{2\lambda_j\lambda_p}{\lambda_j+\lambda_p} \quad \text{and} \quad \alpha_2 = \xi \frac{2}{\lambda_j+\lambda_p} \tag{13}$$

Where λ_j and λ_p are two chosen natural frequencies of the coupled shear wall structures, which are determined by solving the undamped eigenvalue equation:

$$\left|[K]-\lambda^2[M]\right|=0 \tag{14}$$

ξ is the assumed damping ratio for the two chosen modes. In the present analysis, the 1st and 2nd vibration modes are used, and the damping ratio is taken as 5%.

The Newmark-β step-by-step time-integration method is employed to obtain the solution of the dynamic equation. The two parameter β and γ of the Newmark integration are taken as ¼ and ½ respectively. To achieve a reasonable accuracy of the dynamic response of the structure, the time step is made sufficiently small compared with the periods of the first few modes of vibration of the structure.

4. NUMERICAL STUDY

In order to verify the accuracy of the mechanical concept of the proposed method, a typical 25 storey shear wall structures is analyzed. The shear wall is strengthened by bonded CFRP sheets, positioned at the bottom. In this example, the creep and shrinkage effect RC shear walls is taken into account.

On the basis of the presented analysis method, to demonstrate the effect of creep and shrinkage on static and dynamic behavior of RC coupled shear walls, the following data have been used for the numerical results: concrete C25/30, f_{cm}=25 N/mm^2, RH=40%, t_b=28 days, t=120 days, E_{b1}=E_{c28}=30 GPa and β_{sc}=5 (normal or rapid hardening cement).

The numerical values of the geometry and materials properties for shear walls structures are summarized in table 1and table 2.

Table 1. Mechanical properties of materials

Materials	E (GPa)	ν
Concrete	30	0.18
Adhesive	3	0.35
epoxy	3.445	0.35
Carbon	140	0.22

Table 2. Dimensions properties of shear walls structures

Shear wall structures	Dimensions properties			
	Total height (m)	Story height (m)	Wall width (m)	Wall thickness (m)
25 storey	75	3	12	0.25

4.1. Earthquake Records

In general, earthquakes have different properties, such as peak acceleration, duration of strong motion and different ranges of dominant frequencies, and therefore have different influences on the structure. Two earthquake excitations are used in this study. El Asnam and Boumerdes earthquake records (see Table 3 and Figure 2) were selected to investigate the dynamic response of the structure.

Table 3. Properties of earthquake records

Earthquake	Location	Date	Ground acceleration max	Magnitude
El-Asnam	El-Asnam (Chlef)	10-10-1980	0.049g	7.3
Boumerdés	Region Algiers Boumerdés : Keddara	21-05-2003	0.35g	6.8

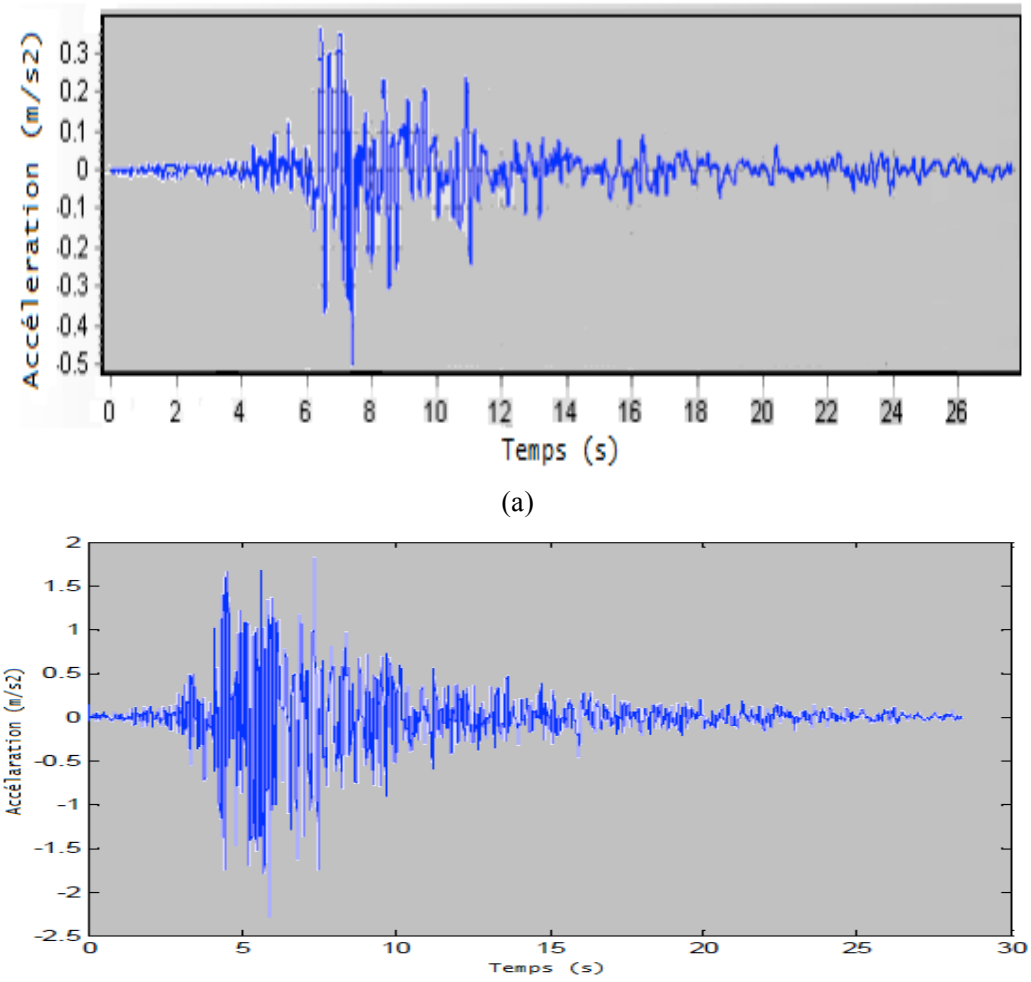
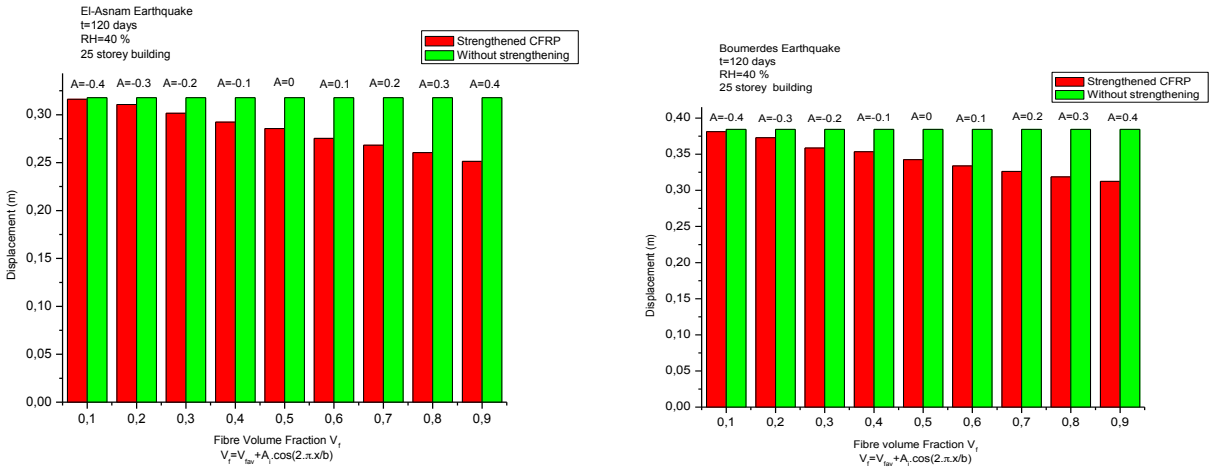


Figure 2. Earthquakes records
(a) El-Asnam and (b) Boumerdés

4.2. Discussion of Results

Firstly, lateral displacements of shear wall structures reinforced with CFRP are compared with those of the reference model (without strengthening), under the two selected earthquakes (El-Asnam and Boumerdes), taking into account the sinusoidal distribution of fibers of the plate and the effect of creep and withdrawal of concrete (age of concrete t = 120 days).. The results are shown in figure 3.

On the other hand, lateral displacements of shear wall structures, reinforced by plates of CFRP are studied under the Boumerdes earthquake, taking into account the effect of creep and shrinkage of concrete (age of concrete t = 120... 5000 days). This effect is reported on figure 4.



(a) (b)

Figure 3. Effect of the fibre volume fraction of composite on displacement

(a) El Asnam et (b) Boumerdes

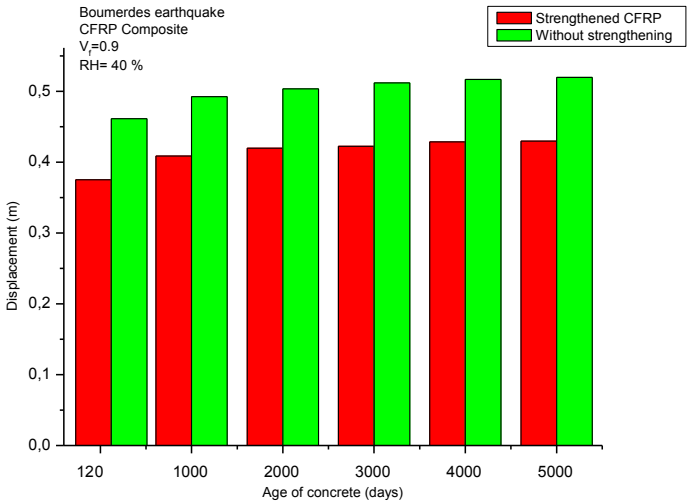


Figure 4. Creep and shrinkage effect on displacement:

Boumerdes earthquake

Analyze the effect of sinusoidal distribution of the fibres of the composite plates used in the present study for the strengthening of the shear wall structures under tested earthquakes and according to the results, we can see that if the volume fraction of the fibers is 0.9, the lateral displacement is falling 20% under El-Asnam earthquake and 18% for Boumerdes earthquake.
The reduction of displacement is proportional to the variation of the fraction of the fibres along the width of the composite plate. Thus, the fibres must be concentrated at the edges of the composite plate where the constraints are the highest.
By the analysis of the effect of creep and shrinkage of concrete on the displacement of the walls, the reduction is proportional to the age of the concrete. Thus, for a young age, the displacement of the walls are tolerable. They become higher over time and stabilize in the long term (generally more than 7000 days).

5. CONCLUSION

The seismic analysis of reinforced concrete shear wall structures strengthened with composite sheets, having variable fibers spacing, including the considerations of the rheological properties of concrete mainly creep and shrinkage has been studied. The analysis is based on the mixed finite element method. The main conclusions that can be drawn from this investigation are:

(a) The proposed model permits the study of lateral stiffness including the opposed effects of creep and shrinkage.
(b) Significant improvement in the displacements was observed when the fibers are clustering near the wall edges, so that they are concentrated.
(c) The evaluated lateral displacements are increased with time due to the predominant action of creep and shrinkage.
(d) The influence of shrinkage action is more significant in the early ageing of concrete.

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