Time-Dependent Behavior of Damaged Reinforced Concrete Shear Walls Strengthened with Composite Plates Having Variable Fibers Spacing

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Abstract**—**In this study, the time-dependent behavior of damaged reinforced concrete shear wall structures strengthened with composite plates having variable fibers spacing was investigated to analyze their seismic response. In the analytical formulation, the adherent and the adhesive layers are all modeled as shear walls, using the mixed Finite Element Method (FEM). The anisotropic damage model is adopted to describe the damage extent of the Reinforced Concrete shear walls. The phenomenon of creep and shrinkage of concrete has been determined by Eurocode 2. Large earthquakes recorded in Algeria (El-Asnam and Boumerdes) have been tested to demonstrate the accuracy of the proposed method.

Numerical results are obtained for non-uniform distributions of carbon fibers in epoxy matrices. The effects of damage extent and the delay mechanism creep and shrinkage of concrete are highlighted. Prospects are being studied.

Keywords**—**RC shear wall structures, composite plates, creep and shrinkage, damaged reinforced concrete structures, finite element method.

I. Introduction

REINFORCED CONCRETE (RC) shear walls are very frequently incorporated into high rise buildings as an efficient means of providing resistance to lateral forces arising from winds and strong ground motions. However, the recent earthquakes, have repeatedly demonstrated the vulnerabilities of the aged or deteriored structures to seismic demands.

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 and, if possible, it not to change the structural scheme of the construction.

Many studies [1], [2] have shown that the carbon fiber reinforced polymer (CFRP) sheets are mechanically effective for upgriding damaged RC structures (RC beams). Therefore, few researches on efficient analyses and experimental studies of strengthened shear walls have been undertaken [3], [4].

In conventional configuration, these plates are made of plies, the fibers within each ply being parallel and uniformly spaced. However, it is possible that significant increases in structural efficiency may be obtained by varying the fibers spacing packing them closely together in regions where great stiffness is needed, but less densely in other regions. Meftah et al. [4] are the first to study the effect of variable fibers spacing on static behavior of RC shear walls strengthened with composite plates.

An important issue in this study is the time-dependent analysis of seismic behavior of damaged RC shear walls strengthened with CFRP sheets having variable fibers spacing. Indeed, in concrete structures, stresses and strains strongly depend on the rheological properties of concrete mainly creep and shrinkage [5].

II. Finite Element for Analysis of Shear Walls

Cheung [6] and Lee [7] 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 [8], by neglecting the lateral strain in the wall, which are generally of little significance. The DOFs can be reduced from 12 to 8. Use of this simplified Cheung's element, which is computationally more efficient, is recommended rather the original Cheung's element. Using the mixed FEM, [8] developed a wall element with the 8 DOFs.

III. Theory and Solution

A. Creep and Shrinkage Effect on the Elastic Deformation of Damaged RC Shear Walls

Assuming that creep and shrinkage are independent, the shrinkage strain $\varepsilon_b^F(y)$ is given as [9]:

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

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:

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

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We note that in (4) $E_b = E_b(t)$ 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 [10]:

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

B. Material Properties of Damaged Shear Walls

Voyiadjis and Kattan [11] proposed an anisotropic damage model, where the elastic energy configuration of deformed and damaged state is equivalent to the elastic energy configuration of deformed but undamaged state. Based on this assumption, the relations of elastic constants of damaged state and undamaged state can be expressed as:

$$E_{11}^d = E_{11}(1-\emptyset_{11})^2 \quad (5)$$

$$G_{12}^d = 4\left(\frac{(1-\emptyset_{11})(1-\emptyset_{22})}{(1-)+(1-\emptyset_{22})}\right)^2 G_{12}$$

whereE_{11}^d,$G_{12}^d$and E_{11},$G_{12}$are the elastic constants of damaged and undamaged state respectively and$\emptyset_{11}$ and $\emptyset_{22}$ are Damage variables. Hence, the material properties of the damaged shear wall can be represented by replacing the above elastic constants with the effective ones defined in (5). A convenient way to determining$\emptyset_{11}$ and $\emptyset_{22}$is to utilize the damage law postulated by [12] and [13] for concrete given as:

$$\emptyset_{22} = \frac{1}{2N_c+1}\left[\frac{\varepsilon_2}{\varepsilon_f^c}\right]^{N_c} \quad (6)$$

$$\emptyset_{11} = H\emptyset_{22},(H > 1) \quad (7)$$

and;

$$N_c = \frac{\sqrt{E_f^c}}{2\left(\sqrt{E_c}-\sqrt{E_f^c}\right)} \quad (8)$$

where E_f^c is the tangential elastic modulus when the stress reaches its peak,E_c is the initial elastic modulus,ε_f^c the failure strain and $\varepsilon_2$the current state of strain. H is a constant determinated by experiments. For example, Ec=49,49 Gpa, Nc=3,65, H=3.

C. Elastic Modulus of Composite Plates Having Variable Spacing

The elastic modulus E_y and G_{xy} for the composite material may be expressed in terms of properties of the fibers and the matrix material by applying the law of mixtures [14]:

$$E_y = E_f\left(V_f + \frac{1-V_f}{R_1}\right) \quad (9)$$

$$G_{xy} = \frac{E_f}{2(1+\upsilon_f)[R_3(1-V_f)+V_f]}$$

where;

$$R_3 = \frac{G_f}{E_m} R_1 = \frac{E_f}{E_m}$$

In (9), the subscripts f and m are used to denote properties of the fiber and matrix respectively and V_f is the volume fraction of the fibre in the composite material. For material having variable fiber spacing [LEI 90], V_f is a function of x, and therefore, E_y , G_{xy} are each functions of x. Suppose, for example, the fiber volume fraction varies parabolically as $V_f = \xi^2$.

D. Stiffness Matrix of the Shear Wall Element

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

$$U^e = U_B^e + U_S^e \quad (10)$$

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:

$$U_B^e = \frac{1}{2}\sum_{i=1}^{3}\int E_y^{(i)}(\varepsilon_b(y))^2\, dx\, dy\, dz \quad (11)$$

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

$$U_S^e = \frac{1}{2}\sum_{i=1}^{3}\int G_{xy}^{(i)}(\gamma(xy))^2\, dx\, dy\, dz \quad (12)$$

E. System Equation of Motion

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

$$[M]\ddot{D}(t) + [C]\dot{D}(t) + [K]D(t) = -[M]E\ddot{D}_g(t) \quad (13)$$

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.

III. 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 Tables I and II.

TABLE I
MECHANICAL PROPERTIES OF MATERIALS

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

TABLE II
DIMENSIONS PROPERTIES OF SHEAR WALLS STRUCTURES

Shear wall structures	Dimensions properties			
	Total height (m)	Story height (m)	Wall width (m)	Wall thickness (m)
20 storey	60	3	18	0.30

A. 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 III) were selected to investigate the dynamic response of the structure.

TABLE III
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

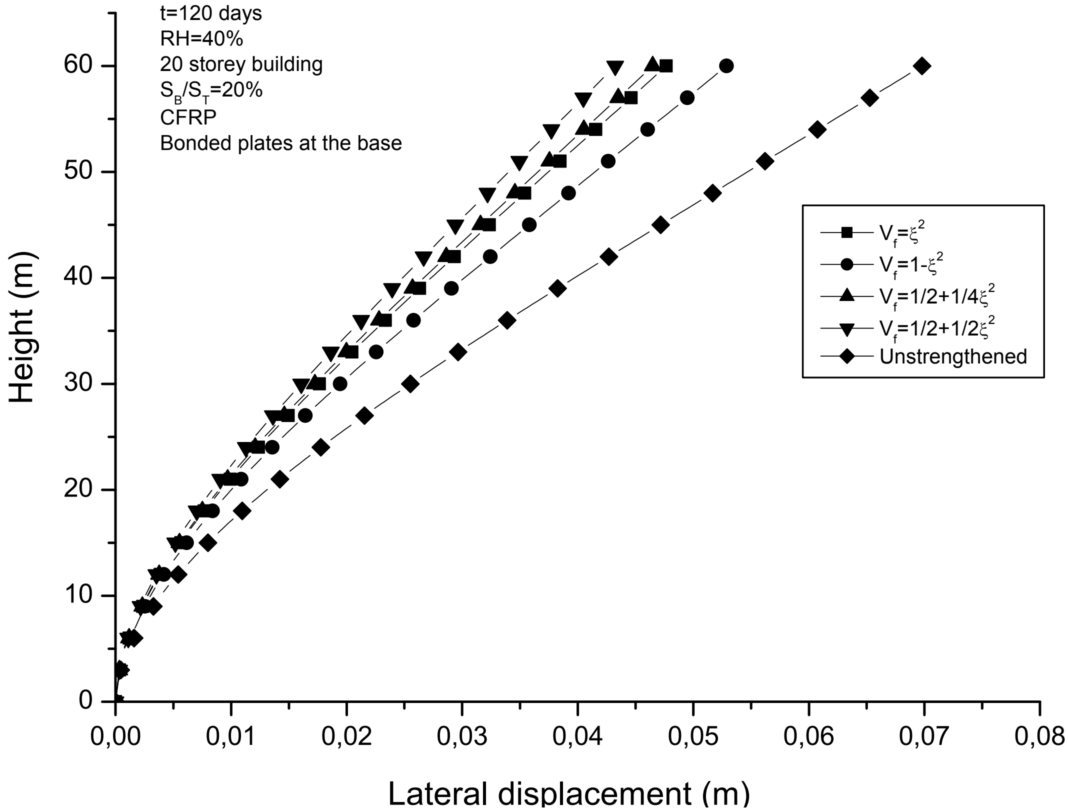

Fig. 1 Effect of the fibers distribution on the lateral displacement of shear wall strengthened

IV. RESULTS

Firstly, lateral displacements of undamaged RC shear walls strengthened with bonded composites plates having variable fibers spacing. In this example, the creep and shrinkage effect is taken into account. This effect is reported on Fig. 1. This 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 effect of creep of concrete (age of concrete t = 120 days).This effect is reported on Fig. 2. On the other hand, lateral displacements of damaged and undamaged shear wall structures, strengthened by plates of CFRP are studied under El-Asnam and Boumerdes earthquake, taking into account the effect of creep and shrinkage of concrete (age of concrete t = 120 days). This effect is reported on Figs. 3 and 4.

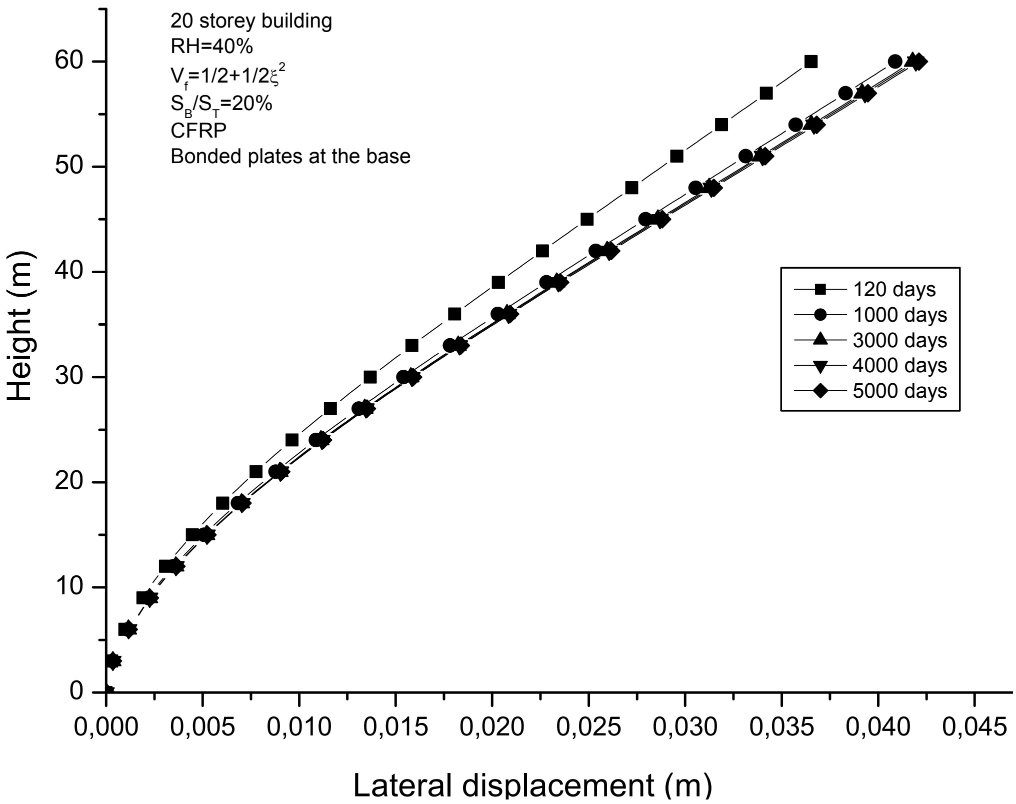

Fig. 2 Effect Time development of lateral displacement for shear wall strengthened

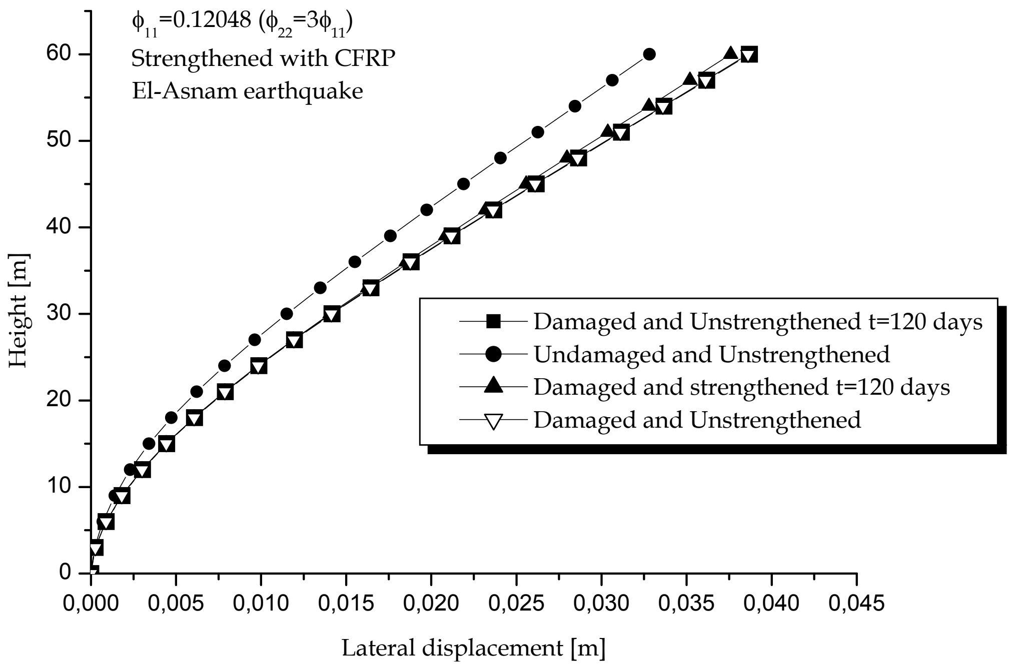

Fig. 3 Effect of damage state on displacement El-Asnam earthquake

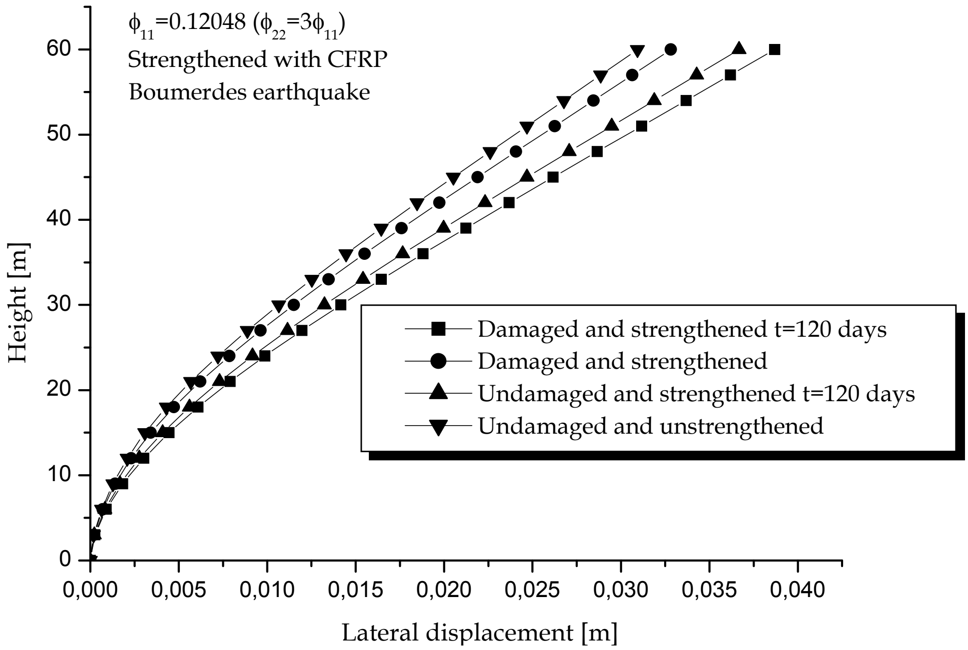

Fig. 4 Effect of damage state on displacement Boumerdes earthquake

IV. Conclusion

The seismic analysis of damaged and undamaged concrete shear walls 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 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 influence of creep action is more significant in the early ageing of concrete.

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