



PUNCHING BEHAVIOR OF CORK PATCHES- STRENGTHENED CONCRETE SLABS.

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Abstract - This paper aims to introduce a nonlinear finite element modeling (NLFEM) to predict the punching behavior of concrete slabs strengthened with bonded composite cork based-patches. The influence of the variation of the thickness of the cork composite plate, subjected to dynamic loads, on the performances of the slab, are measured and analyzed to investigate the effectiveness of strengthening. Several variations are considered such as a thickness of 2, 3, 4 and 5 mm of the composite plate. Simulations are carried out on full 3D slabs subjected to dynamic loads taking into account the real experimental behavior of all consecutive materials, namely: a combined plastic-damage model is used to describe the nonlinear properties of concrete, while, cork based-patches are modeled according to as an



orthotropic elastic one. The emphasized numerical results in terms of bearing capacity and damage values highlight the effectiveness of the slabs reinforcement technique.

Keywords–NLFEM/cork based-patches/strengthened slabs/centered shock-load/punching.

Résumé - Ce document vise à introduire une modélisation par éléments finis non linéaires (NLFEM) afin de prédire le comportement au poinçonnement des dalles de béton renforcées par collage de patchs composites à base de liège. L'influence de la variation de l'épaisseur du patch composite en liège, soumis à des charges dynamiques, sur les performances de la dalle, est mesurée et analysée pour étudier l'efficacité du renforcement. Plusieurs variantes sont considérées telles qu'une épaisseur de 2, 3, 4 et 5 mm du patch composite. Les simulations sont effectuées sur des dalles 3D soumises à des charges dynamiques prenant en compte le comportement expérimental réel de tous les matériaux consécutifs, à savoir: un modèle de dommage plastique combiné est utilisé pour décrire les propriétés non linéaires du béton, tandis que les patchs à base de liège sont modélisés selon un modèle élastique orthotrope. Les résultats numériques mis en évidence en termes de capacité portante et de valeurs de dommages soulignent l'efficacité de la technique de renforcement des dalles.



Mots clés –NLFEM/patchs à base de liège/dalles renforcées/charge de choc centrée/poinçonnement.

Nomenclature

ϕ Angle de dilatation

ν Coefficient de Poisson

f_c Contrainte de compression (Mpa)

f_t Contrainte de rupture en traction (Mpa)

σ Contrainte réel

ν_{12} Coefficient de Poison longitudinal

ν_{13} Coefficient de Poison transversal

D_0^{el} : Matrice de raideur élastique.

$D^{el} = (1 - d)D_0^{el}$: Matrice de raideur après endommagement.

G_{12} Module de cisaillement (Gpa)

E_1 Module longitudinal (Gpa)

E_2 Module transversal (Gpa)



E_c Module de young (Gpa)

S Résistance au cisaillement (Mpa)

$\bar{\sigma}$: Tenseur de contrainte effective.

d : Variable scalaire unique d'endommagement.

1. Introduction

In last decades, the usage of bonded-composites in the repair and strengthening of concrete members has experienced significant progress and presents competitive issues in terms of performances enhancing [1]. Around the world, the many researches carried out on composites in construction have agreed the ability of fibre-reinforced polymer composites to improve the carrying capacities of beams and slabs when bonded to their tension surfaces [2], [3] et [4]. Indeed, concrete and RC slabs have been experimentally and numerically focused [5], [6], as global findings these investigations have proven that FRP-strengthened slabs when subjected to punctual loads; they develop more resistance, ductility and failure energy [7]. In most general cases, concrete slabs failure is due to the shear stress significantly developed in the compressed zone [8],



[9], [10] et [11]. In fact, deterioration of the concrete material is resulted by major loss of strength and other efficiencies, which require structural reinforcement to improve the mechanical characteristics of all slab constitutive materials [12] et [13]. Actually, behavior analysis of FRP-strengthened concrete slabs subjected to dynamic loading is a very current theme. Soufeiani et al[2] have investigated on the effect of laminate stacking sequence and fiber orientation on the dynamic response of FRP composite slabs using finite element techniques. As main conclusions, authors have shown that both criteria of composite responses in terms of displacement and acceleration are required to ensure compliance with the comfort level limits and degree layers play a significant role in the dynamic responses of the structure. Kheloui.Taouche et al[14] studied the height of projectile influence on the performances of cork patches-strengthened concrete slabs. This later has proven that damages are greatly reduced by bending strength and impact forces, also, the dynamic parameters of concrete slabs were highly influenced by the drop height of the



masses well as the mechanical and geometrical properties of the composite plate.

Moreover, our contribution in this paper is to propose a FEM able to predict the punching behavior of strengthened-concrete slabs, and to complement the already drawn conclusions in the aforementioned references. Hence, nonlinear finite element modeling based on a local approach is carried out to simulate the real behavior of such members in order to allow a better understanding of behavior of this reinforced slab. The influence of the variation of the cork composite plate thickness subjected to dynamic loads is focused to investigate the effectiveness of strengthening. Numerical results in terms of local and overall behavior are emphasized and analyzed, namely: stresses and damages morphology, global load-deflection response and stress-strain one. The confrontation clearly shows the effectiveness of cork patches-strengthened concrete slabs compared to conventional ones under centered shock-projectile.

2. FEM of designed slabs

Numerical simulations with parametric FEM are powerful and robust tools for comprehensive investigations of punching behavior of studied slabs. In this respect, flexural capacities and failure mechanisms of new reinforced slabs by bonded cork composite patches upon the subjected face to dynamic loads. Under constant high of mass drop, several variations of cork patches thickness are considered namely: 2, 3, 4 and 5 mm. In fact, the below sections precise the simulation procedure and used laws materials. Geometrical model for simulated concrete slab is illustrated in figure 1.

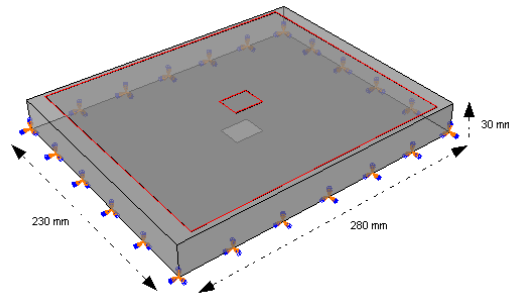


Figure 1. Geometrical model for simulated concrete slab.

2.1. Materials models

Concrete is assumed as an isotropic elastic-plastic material, while composite patch an orthotropic elastic one. Both considered materials were modeled according to solid deformable elements. Concrete damaged plasticity model which takes into account the dissymmetry of the concrete behavior in compression and in tension, is used [8]. Plasticity problems associated with damage are considered, it assumes that the two main mechanisms of rupture are cracking and crushing of concrete in compression. The stress-strain relation is defined by equation (1) as following:

$$\sigma = (1 - d)D_0^{el} : (\varepsilon - \varepsilon^{pl}) = D^{el} : (\varepsilon - \varepsilon^{pl}) \quad (1)$$

Where D_0^{el} and $\bar{\sigma}$ are respectively, the matrix of elastic stiffness and the effective stress tensor. The stiffness matrix after damage is given by equation (2) as follows:

$$D^{el} = (1 - d) D_0^{el} \quad (2)$$

The use of the effective stress principle leads to a relation

associating the real stress to the effective stress, allowing us to connect the effective stress tensor to the elastic stress tensor by $\sigma = (1 - d)\bar{\sigma}$ which allows them to combine the effective stress tensor to the elastic stress tensor by relation (3):

$$\bar{\sigma} = D_0^{el} : (\varepsilon - \varepsilon^{pl}) \quad (3)$$

The degree of concrete degradation under external loading is represented by a single scalar variable of damage "d" affecting the Young's modulus, with dissymmetric values respectively in compression and tension. The models parameters are obtained under axial and tri-axial loads, the axial ones were experimentally determined. Table 1 summarizes the concrete model parameters used in slabs FEM. Cork based-patches are modeled according to an elastic orthotropic model in the hypothesis of plan stresses with the Hill-Tsai rupture criterion. The stiffness and rupture parameters of this model were identified from the characterization tests.



Table 1. Concrete model parameters

Proprieties	Values
f_c Compressive stress (Mpa)	27
f_t Yield stress on tension (Mpa)	2.3
E_c Young Modulus (Gpa)	31
ν Poisson's ratio	0.19
ϕ Angle of dilatation	34
α_e Parameter of the flow potential	0.1

Table 2. Cork based-patches parameters

Proprieties	Values
E_1 Longitudinal modulus (Gpa)	80
E_2 Transversal modulus (Gpa)	14
G_{12} Shear modulus (Gpa)	5
ν_{12} Longitudinal poison's ratio	0.26
ν_{13} Transversal poison's ratio	0.31
S Shear strength (Mpa)	75

The elastic behavior of cork patches measured by tensile, compressive, and shear test system are given in Table 2. They were modeled using Tsai-Wu failure criterion in the case of anisotropic materials.

2.2. Meshing and load devises

Based on finite element method, modeling of geometrical specimens is conducted in full 3D nonlinear finite element analysis. After identifying of all materials parameters and geometrical properties of cork based patches and concrete slabs mesh sensitivity is performed. Concrete solid is meshed in the sensitive zones to failure, with 25 mm tetrahedral finite element (3D) models, with the Lagrange formulation (C3D8). An anisotropic formulation has been adopted for composite patches, which were modeled with 10 mm 2D quadratic finite elements and four nodes with 8 degrees of freedom. The meshing configurations of reinforced slabs by bonded cork composite patches are depicted in Figure 2.

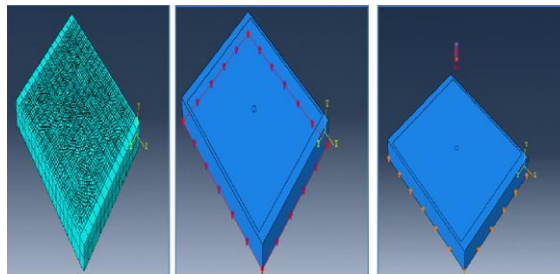


Figure 2: Modeling procedure: Meshing, Boundary Conditions, and Impact Load Mode.



Slabs with various configuration of patches thickness were subjected to shock-projectile loads applied upon a rectangle impact with (28×23) mm² dimensions. The actual loading is applied on the top face of the slabs, while the bottom one was bonded with composite patches. All considered models loaded with the same conditions similarly to experiments. The modeling of shock loading is carried out using a cylindrical steel projectile of 3 kg mass with a constant loading speed of 0.15 m / s. However, the initial height of the projectile is remained constant.

2.3. FEM validation

In order to verify the proposed finite element model, the mechanical proprieties of all materials and the geometrical characteristics mentioned in the above sections are modeled. Experimental data carried out on similar FRP patches-strengthened slabs under statically punching loads reported in aforementioned reference [4] were used to validate simulations to a better assessment of slabs punching capacity. The confrontation of an experimental and numerical punching loads VS deflection is given by figure 3.

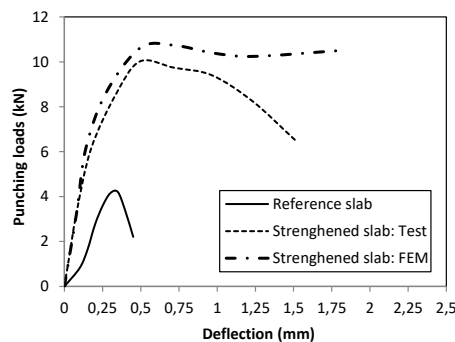


Figure 3: Validation of the proposed finite element model.

A satisfactory agreement between simulation and experimental results in terms of overall behavior of the considered slabs under statically centered load is observed. The comparison shows that the

average bearing capacity of the strengthened slab observed during experiments was around of 10 kN, while the ultimate strength obtained by the proposed FEM is found to be 11 kN. On the other hand, the difference between the proposed analysis model and the experiments is <5%, which is less than standard experimental scatter.

3.Simulation results

NLFEM results in terms of compressive and tensile damages evolution are emphasized in order to highlight the failure morphology of modeled slabs. Figure 4 shows the damage response under impact loading for the various thicknesses of cork based-patches. According to applied dynamic loads, a significant evolution of stresses in two considered specimens is recorded. Stresses field appears first in the impact point for both specimens, and then mainly propagate according to inclined rods in the reference slab. Unlike, the strengthened one, which presents an acceptable level of strength and punching stiffness. Indeed, results analysis in terms of damages evolution shows that the control slabs are strongly

damaged compared to reinforce one. The conjugation of cork based-patches performances allows to considerably reducing damages. The thickness of cork based-patches significantly affect the strength, ductility and intrinsic mechanical parameters of studied slabs. The ultimate load improvement is accompanied by an increase in ductility that results an increase in fracture energy compared to concrete slabs.

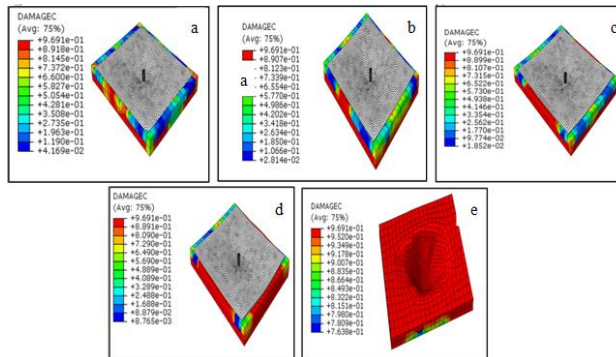


Figure 4: Evolution of slabs damages for various patches thickness:

a: 2mm, b: 3mm, c: 4mm, d: 5mm, e: Reference Slab.

On the other hand, the evolution of applied loading versus deflection investigated slabs, as well as the confrontation of stress-strain curves are shown in Figure 5 and Figure 6.

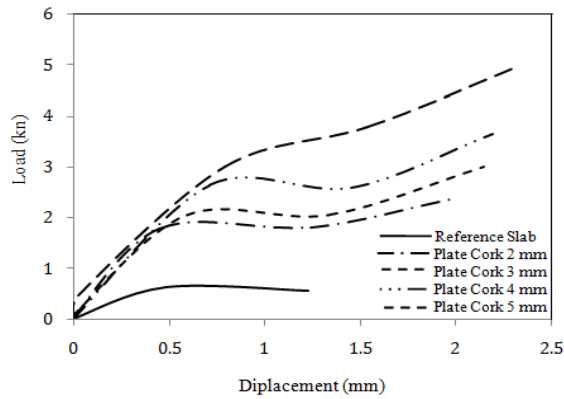


Figure 5: Load- deflection curves: overall vs. local response.

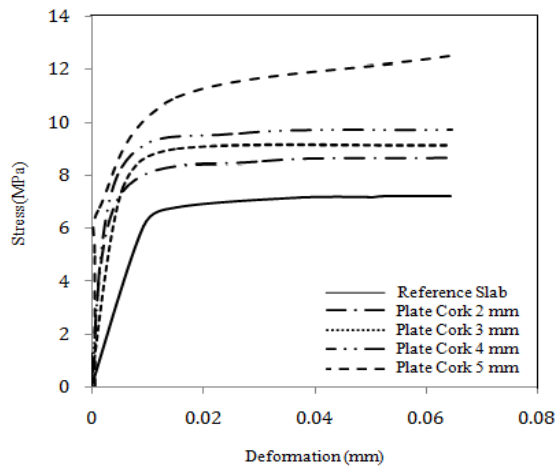


Figure 6: Stress-strain curves: overall vs. local response.

The confrontation of load-deflection curves shows the positive contribution in terms of punching capacity, which is around of 90%



compared to reference slab. Strengthened slab with 5 mm thickness of cork patch presents an average load capacity of 5000 N and a corresponding mid-span deflection of 2.30 mm. The reference slab with a less punching capacity around 1000 N and 1.20 mm corresponding deflection. The other configurations of patches thickness present approximately similar punching capacities as depicted in figure 5.

4.Conclusion

The present paper focuses the behavior of cork patches-strengthened concrete slabs under centered shock-projectile. The final discussion aforementioned illustrates the advantages of the proposed NLFEM approach which has proved that bonded composite materials seems to be a promising technique for reinforcing concrete structures. However, to reduce the cost of the reinforcement operation (reduction of the quantity of composite materials), it is recommended to use composite patches to cover the most stressed area, in the case of progressive axial loading. The reinforcement of concrete members improves the mechanical



characteristics and provides better behavior. In cases of strengthened slabs, mechanical and geometrical properties of the plan dimensions and the position of the composite patch significantly affect the global behavior. The emphasized results highlight the effect of composite patches, with respect to their thickness, on improving the mechanical properties of the concrete slab in terms of strength and ductility.

The confrontation shows a satisfactory agreement between all simulated members, so the finite element analysis can be used for an effective analyzing of the behavior of strengthened-concrete slabs to carry out a parametric analysis. Finally, authors believe that, other parameters governing the behavior are to be focused, to put forward and to develop all the interest and applicability of this proposed technique of reinforcement.

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