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Numerical Investigation of the Jacketing Method of Reinforced Concrete Column

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***Abstract*—**The first intent of this study is to develop a finite element model that can predict correctly the behavior of the reinforced concrete column. Second aim is to use the finite element model to investigate and evaluate the effect of the strengthening method by jacketing of the reinforced concrete column, by considering different interface contact between the old and the new concrete. Four models were evaluated, one by considering perfect contact, the other three models by using friction coefficient of 0.1, 0.3 and 0.5. The simulation was carried out by using Abaqus software. The obtained results show that the jacketing reinforcement led to significant increase of the global performance of the behavior of the simulated reinforced concrete column.

***Keywords*—**Strengthening, jacketing, reinforced concrete column, 3D simulation, Abaqus.

I. INTRODUCTION

REINFORCED concrete structures are sometimes subject to extreme loading such as shocks and earthquakes and the consequences can be disastrous. The vulnerability reduction to the earthquake of the existing building is a major social issue. Strengthening of structural elements as reinforced concrete column by jacketing method offers an interesting solution [1], [2], but the design rules concerning the application of such method for seismic reinforcement design have not yet been clearly established [3].

The purpose of this study is to evaluate and to investigate the effectiveness of different strengthening configurations by jacketing of reinforced concrete column by finite element method.

Finite element modeling of reinforced concrete column requires a rigorous application of the method and a number of idealization and complexities involved in reinforced concrete. For this, only 3D modeling can take into account all the effects related to the reinforced concrete such as contact interface between concrete-concrete and concrete-reinforcement that are important for jacketing investigation. In addition, the 3D modeling can represent the local and global behavior at the same time.

To achieve the aim of this study, ABAQUS software [4] has been used to develop the finite element model for column and to validate respect to experiment results. After validation of the model, the investigation of the jacketing is done.

II. EXPERIMENTAL MODEL

A. Overview of the Sample

The experimental sample retained in this study is derived from the experimental testing carried out on a large scale on reinforced concrete columns with different reinforcement configurations tested by [5]. The experimental testing focused on 8 columns with a cross section of 0.25 x 0.37 x 2.50 m^3 and height of 2.50 m. The reinforcement of the columns was dimensioned according to the minimal rules of the BAEL thus allowing the columns to present characteristics close to those of the old constructions, not subjected to a seismic design (see Fig. 1).

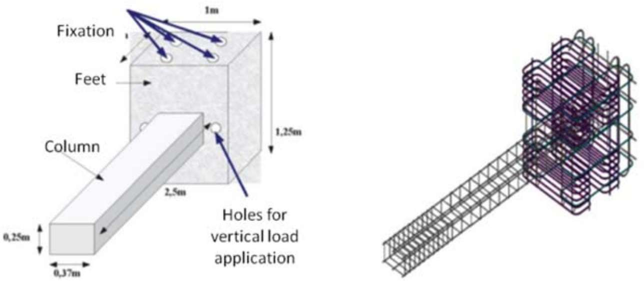

Fig. 1 Geometry and reinforcement of the sample used in the present study

Six reinforcement bars of 10 mm diameter were used for longitudinal reinforcement as well as 6 mm diameter of strips reinforcement spaced by 150 mm for transversal reinforcement. The strips were spaced by 75 mm at the top of the column (80 cm high) in order to avoid the shear force induced by the application of the lateral force.

The mechanical characteristics of the used concrete and reinforcement steel are presented in Tables I and II.

TABLE I
MECHANICAL CHARACTERISTICS OF THE STEEL REINFORCEMENT

Steel	H10	HA6
Young Modulus (MPa)	195000	185000
Yield Stress (MPa)	390	555
Yield Stain	0.002	0.003
Max Stress (MPa)	603	614
Max Strain	0.037	0.021
Poisson’s ratio	0.3	0.3

Fig. 2 represents the loading protocol used by [5]. A constant axial force of 700 kN is applied vertically at the head of the column. This load is representative of the permanent

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load acting of the column at the building scale. Once the axial load is applied, an imposed displacement is applied until the failure of the column.

TABLE II
MECHANICAL CHARACTERISTICS OF CONCRETE

Concrete	Value (MPa)
Young Modulus	27300
Compressive strength	46.2
Tensile strength	3.6
Poisson’s ratio	0.3

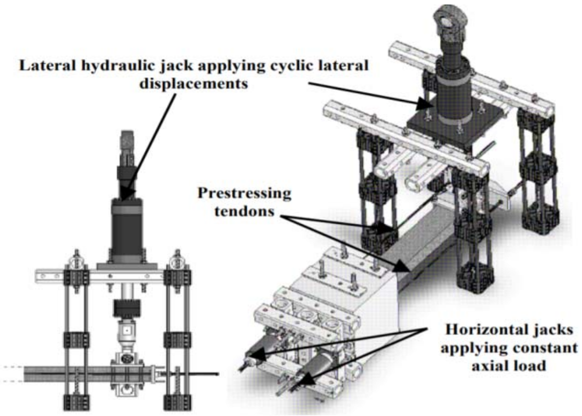

Fig. 2 Testing protocol

III. FINITE ELEMENT MODEL

In this section, a description of the modeling approaches and the techniques used in this study are presented.

A. Geometrical Modeling

Fig. 3 represents the finite element idealization of the reinforced concrete column by including all the physical parts.

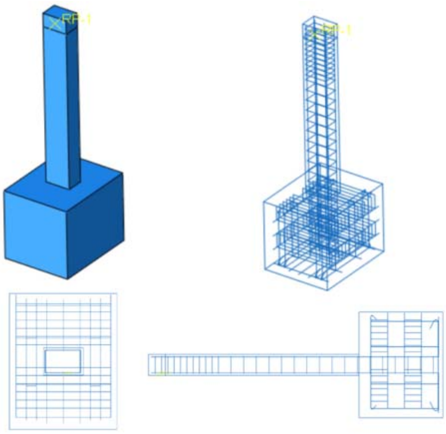

Fig. 3 Finite element idealization (Geometry and reinforcement)

B. Loading and Boundary Conditions

Fig. 4 represents the loading and the boundary conditions acting on the column. These conditions are exactly the same as those used on the experiment testing. The feet of the reinforced concrete column is considered as fixed, so all the degree of foredoom are fixed (no translation and rotation allowed). In the simulation, a constant vertical load of 700Kn is applied as a first load step. In the second step of the loading, an imposed displacement is applied on the head of the reinforced concrete until the failure.

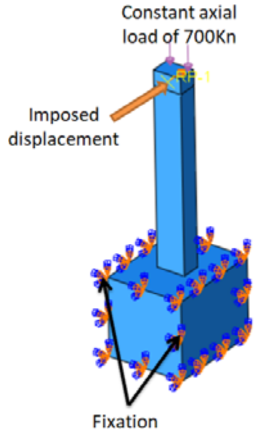

Fig. 4 Loading and boundaries condition

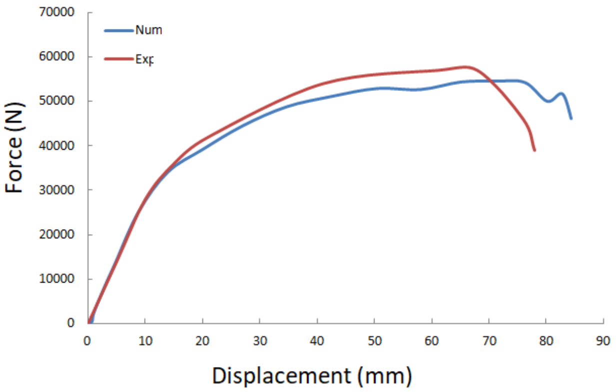

Fig. 5 Comparison of the experiment and numeric force-displacement curves

C. Material Law Behavior

The constitutive behavior of steel bars reinforcement is modeled using an elastic plastic model. The parameters used to define model under ABAQUS are elastic modulus E and the plastic stress-strain curve.

For the concrete, the concrete damage model is used. In this model the uniaxial curves of stress-strain and damage-strain for tensile and compression are necessary to describe the unixial behavior of the concrete. The multi-axial behaviour is defined by the following parameters: the ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress ($\sigma b0/\sigma c0$), the ratio of the second deviatoric stress invariant on the tensile meridian to that on the compressive meridian (Kc), the eccentricity ($\in$) and the dilation angle (ψ) parameter for the flow potential. These parameters define the multi-axial response as complicated to be defined experimentally [6] for this, the default values given by Abaqus are used.

For detailed information on the law behavior of concrete and all the parameters and the values please refer to [7].

D.Results and Validation

Fig. 5 represents the force-displacement curve comparison between the experiment and the finite element model. On Fig. 5, it can be seen that the behavior of the column is linear elastic until a force of 36 kN and correspondent displacement of 15 mm. The comparison of both curves (experiment curve and numerical curve) shows that the finite element model predicted exactly the experiment behavior. After a force of 36 kN and displacement of 15 mm, the behavior of the column becomes plastic and the comparison of both curves shows that the finite element model is in good agreement with the experiment. The ultimate force for the experiment is around 57 kN and for the finite element model is 54.33 kN, so the correlation of the finite element model respect to the experiment is about 95.9%.

Fig. 6 Comparison of the local failure

Fig. 6 represents the comparison of the damage in the experiment and the finite element model results. This figure shows that the experimental model had a failure of combination of compressive and tensile failure and the both of the damage are predicted by the finite element model.

As conclusion of the validation study, the model is able to predict the global and locally the whole behavior of the column correctly.

IV. STRENGTHENING STUDY

The validate model will be jacketed by reinforced concrete band of 5 cm that include reinforcement bars as shown in Fig. 7.

In this section, we will focus on the evaluation of the jacketing of the strengthening of reinforced concrete column affected by the interface contact of the old and the new concrete. For this, four configuration of the contact interface are taken into account as: (a) perfect contact between the old and new concrete; (b) using a penalty method contact for the interface of the old and new concrete by using a friction coefficient of 0.1, 0.3 and 0.5.

A. Results and Discussion

Fig. 7 represents the force-displacement curves obtained for the different friction coefficients and a perfect contact compared to unjacketed model. In the curve, the reference model or unjacketed model is nominated MC, the jacketed model with perfect contact is nominated MCPR5 and the other jacketed models with friction coefficient contact are nominated MR5F0.1, MR5F0.3 and MR5F0.5 for the contact coefficient of 0.1, 0.3 and 0.5, respectively.

From Fig. 7, it can be seen that the jacketing of the reference model leads to significatively increasing the whole performance of the reinforced concrete column. The initial stiffness related to the elastic phase as well as plastic phase are changed in important way compared to the unjacketed model.

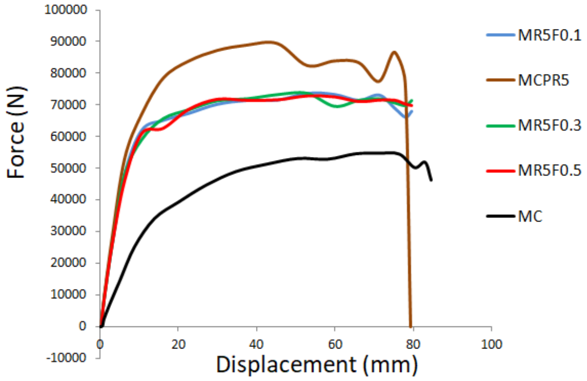

Fig. 7 Curves' comparison

Table III represents the comparison of the ultimate load of all the studied models. In this table it can be seen that the jacketed model with perfect contact (MCPR5) is given the best performance of the column respect to the unjacketed model (MC) and the models with friction interface. Nevertheless, the models MR5F 0.1, MR5F0.3 and MR5F 0.5 with friction contact gave better results that the model MC.

TABLE III
COMPARISON OF THE ULTIMATE LOAD RESPECT TO THE UNJACKETED MODEL

Model	Ultimate load	Ultimate load/Ultimate load of MC
MC	54.66	/
MCPR5	89.55	1.63
MR5F0.1	73.78	1.35
MR5F0.3	73.74	1.35
MR5F0.5	72.95	1.33

The MCPR5 has a load gain of 63% respect to the MC model. The friction models (MR5FE0.1, MR5F0.3 and MR5F0.5) have a load gain of 35% respect to the MC model. The MCPR5 has a load gain of 21% with respect to the friction models. It can be noticed the friction models gave approximately the same results.

V. CONCLUSION

The study presented in this paper had a focus on the benefit of the strengthening of the reinforced concrete column by jacketing and the keys conclusions are:

1) The developed finite element model has the ability to predict correctly the local and global behavior with all the details related to the damage and the failure of the concrete and the reinforcement.
2) The jacketed models show a significant improvement of the whole behavior of the reinforced concrete column.
3) The variation of the friction coefficient has not an impact on the response.

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