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# Numerical Modelling and analysis of a node reinforced by CFRP solicited by an approximate seismic effort

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**Abstract**

The present paper presents the results of a finite element numerical modelling of reinforced concrete separated nodes, these nodes were reinforced by carbon fibre and analysed to deduce the relationship between reinforcement critical areas of the node and ductile behaviour of this node to meet the earthquake resistant requirements laid out in Moroccan seismic regulations.

This paper comes out with a direct relationship between the seismic effort and the number of tissue layer needed for node strengthening depending on the intrinsic characteristics of the tissue.

Then the article discusses a comparison between two models of an unreinforced and stressed node and of the same node reinforced and stressed. The results clearly show a decrease in stresses in the reinforced case.

The conclusions of this work can be useful for the reinforcement of the old buildings conceived and built before the appearance of the seismic regulation thus to put in seismic conformity the old buildings which are object of rehabilitation, extension or reinforcement.

**Keywords:** Structure, Modeling, Strengthening, Fibers, Carbon, Polymer.

## I. INTRODUCTION

Reinforced concrete structures built before the start of seismic regulation have a serious problem in making them comply with the said regulations.

It is required in the RPS 2000 (Moroccan Seismic Regulation), version 2011 [1]

• Ensure continuity of steels in critical areas

• And to have confinement reinforcement in these areas

• To use longitudinal reinforcements High adherence with a minimum diameter of 10mm

• To guarantee a minimum dimension for sections

• At the node level, we require

- To satisfy the inequality $\Sigma\,|\,Mc\,|\geqslant 1{,}15\Sigma\,|\,Mp\,|$ where $Mc$ and $Mp$ are respectively the resistant moments at the column and beam related to this node.
- Ensure the continuity of steels in the nodes.
- Arrange a confinement reinforcement.

In the following paragraphs, we will discuss the confinement requirements for a typical node and propose ways to ensure this confinement by using the CFRP products available in the market, and then deduce a simple relationship between the number of layers CFRP bonded to the concrete via a special resin to ensure the confinement of the node and thus meet the requirements of seismic regulation ensuring ductility at the node.

## II. RECOMMENDATIONS FOR ENSURING CONTINUITY OF REINFORCEMENT

The continuity of the longitudinal reinforcement in the columns is ensured. It remains to ensure the longitudinal reinforcement beams.

The supplier Freyssinet proposes rods (bars) in CFRP pultruded called Foreva® RFC. They are intended to play the role of reinforcements by only reserving them grooves in the coating of elements in RC (remember that CFRP have the immense advantage of not being corrodible.) [2]

No technical notice (defining, inter alia, the mechanical characteristics of the product, the safety factors, the adhesion properties, etc.) relating to this reinforcing process is published by the manufacturer. We cannot therefore size this process.

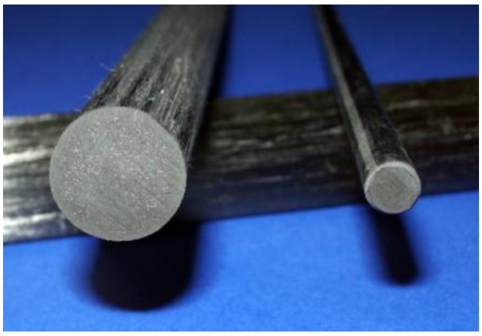

**Fig. 1.** Pultruded CFRP rods

A schema showing these rods put in place is shown in the figure below. [3]

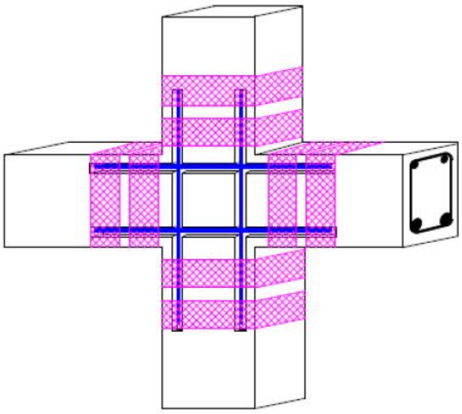

**Fig. 2.** The continuity of the reinforcement in a node ensured by CFRP rods

## III. THE CONFINEMENT

### III.I The effect of confinement on ductility

In the case of an earthquake, the structure is allowed to laminate in places. It is therefore necessary to give it a high ductility, a large capacity of deformation in the plastic field before the ruin.

The most likely places to laminate are so-called critical areas. In these areas it is admitted that they can develop what are called plastic kneecaps, hence the need to increase the ductility. [4]

It is known that the confinement of the elements contributes to increase their ductility. Commonly in reinforced concrete, the confinement is ensured by the transverse reinforcements.

### III.II Confinement of critical areas

Only continuous spirals, frames, stirrups and pins are cited in the RPS2000 Version 2011 (Moroccan seismic Regulation), to ensure minimal confinement. We only indicate the spacing required between these reinforcements, we do not speak about confining pressure.

We translate the spacings required by the RPS2000 V2011 into confinement stresses in the sense of the formula

$$\sigma 2=\alpha \rho_{sx} f_{yw} \quad (1)$$

Which is given in Eurocode 8, Part 3: building evaluation and reinforcement, in paragraph (7) b of Article A.3.2. [5]

α is the coefficient of effectiveness of confinement, given by

$$\alpha = \left(1-\frac{Sh}{2b0}\right)\left(1-\frac{Sh}{2h0}\right)\left(1-\frac{\Sigma \mathrm{bi}^2}{6h0b0}\right)$$

According to the RPS2000 V2011, in the columns

$$\mathrm{Sh}=\min\,(8\Phi L\ ;0{,}25b_0\ ;15cm).$$

Sh is the spacing of transverse steels, $\Phi L$ is the diameter of longitudinal steels, h0 et b0 are the sections of the bar, $\rho_{sx}$ is the percentage of transverse steel, and $f_{yw}$ is the elasticity modulus of the steel.

Ep is the confinement module that expresses its rigidity.

$$\mathrm{Ep} = \frac{2tf.np}{b}\,Ef \quad [6] \qquad (2)$$

Ep equivalent in our case to the confinement stress σ2

($tf$ is the thickness of the reinforcement, $b$ the long side of the beam, $np$ the number of reinforcing plies and Ef is the Elasticity module) The coefficient 2 comes from the fact that the composite opposes transversal deformation in each direction by its section in both sides.

From equations (1) and (2), it is concluded that:

$$np \geq \frac{b\ \sigma 2}{2\ tf\ Ef}$$

## IV. MODELISATION

### IV.I Presentation

It is a question of modelling a typical node presenting the intersection of two elements in RC in general a column with a beam, and then modelling the tissue of CFRP by admitting an equivalent approach of adhesion between the tissue and the concrete. [7; 8]

The modelling will be done with RSA 2019 software (Robot Structural Analysis), which allows to use the finite element method to analyse the behaviour of the structures.

The objective is to load the beam with progressive horizontal seismic effort and see the reaction of the loaded element with and without CFRP reinforcement tissue.

**Table 1.** The characteristics of the concrete

| | |
|---|---|
| Compressive strength fc28 | 25 Mpa |
| Young's modulus E | 32 000 Mpa |
| Coefficient of fish ʋ | 0,2 |
| Shear modulus G | 13 300 Mpa |
| Specific weight | 2,5 T/m3 |
| Thermal expansion | 0,000010 1/°C |

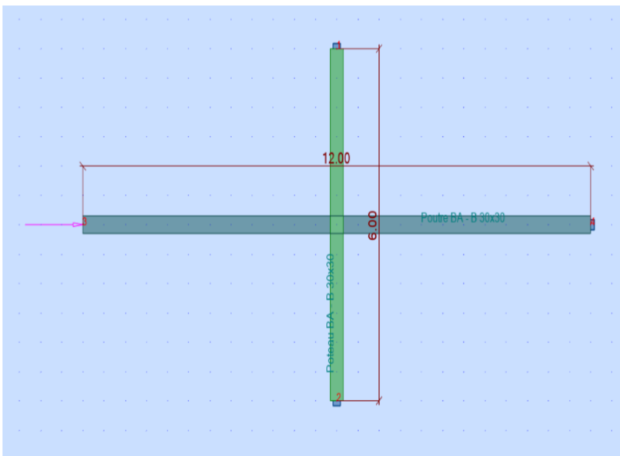


**Fig. 3.** Node type in RC

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The characteristics of the bars are summarized in the table 2:

**Table 2.** Characteristics of bars in RC

| | Section (cm) | Length (m) | Conditions to the limits |
|---|---|---|---|
| column | 30x30 | 6 | Encastred-Encastred |
| beam | 30x30 | 12 | Free- Encastred |

Below (chapter IV.II) are the results of the forces, moments and stresses in the two elements of the node by applying progressive horizontal forces of 20, 40 and 60 Tons (we chose these values since they are values commonly encountered in seismic stresses according to the zoning and the height of the building).

### IV.II Node modelling without reinforcement

The table below (Table 3) summarize the results of the forces and stresses in the two elements of reinforced concrete (column and beam) solicited with a horizontal load and without resorting to any reinforcement of the node.

**Table 3.** Efforts, moments and stresses in bars without CFRP reinforcement

| Effort applied to the node | Bar / Node | Fx [T] | Fy[T] | Fz [T] | Mx [T.m] | My [T.m] | Mz [T.m] | Smax [Mpa] | Smin [Mpa] | Fx/Ax [Mpa] |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 T | Column/01 | 0 | -0,38 | 1,88 | -0,82 | -2,49 | -0,58 | 6,67 | -6,67 | 0 |
| | Column /02 | 0 | 0,38 | -1,88 | 0,82 | -2,49 | -0,58 | 6,67 | -6,67 | 0 |
| | Beam/03 | 20 | 0 | 0 | 0 | 0 | 0 | 2,18 | 2,18 | 2,18 |
| | Beam /04 | 19,23 | 0 | -0,29 | 0 | -0,09 | 0 | 2,3 | 1,89 | 2,1 |
| 40 T | Column /01 | 0 | -0,77 | 1,88 | -0,82 | -2,49 | -1,15 | 7,93 | -7,93 | 0 |
| | Column /02 | 0 | 0,77 | -1,88 | 0,82 | -2,49 | -1,15 | 7,93 | -7,93 | 0 |
| | Beam /03 | 40 | 0 | 0 | 0 | 0 | 0 | 4,36 | 4,36 | 4,36 |
| | Beam /04 | 38,46 | 0 | -0,29 | 0 | -0,09 | 0 | 4,39 | 3,99 | 4,19 |
| 60 T | Column /01 | 0 | -1,15 | 1,88 | -0,82 | -2,49 | -1,73 | 9,19 | -9,19 | 0 |
| | Column /02 | 0 | 1,15 | -1,88 | 0,82 | -2,49 | -1,73 | 9,19 | -9,19 | 0 |
| | Beam /03 | 60 | 0 | 0 | 0 | 0 | 0 | 6,54 | 6,54 | 6,54 |
| | Beam /04 | 57,69 | 0 | -0,29 | 0 | -0,09 | 0 | 6,49 | 6,08 | 6,29 |

Below is an example of a diagram corresponding to a horizontal force of 20 T

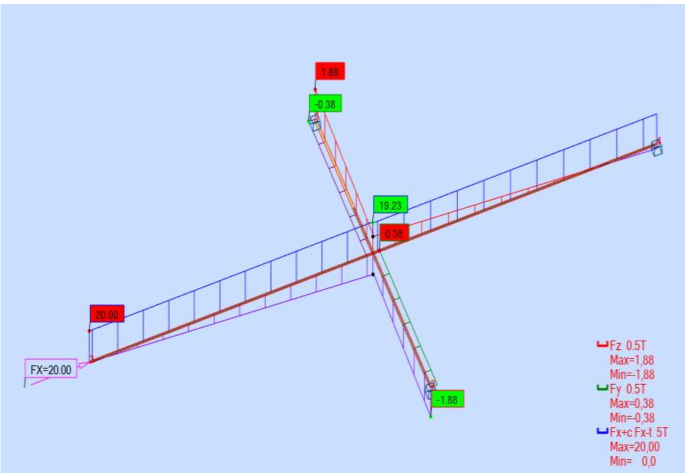


**Fig. 4.** Diagram of forces in bars without CFRP reinforcement

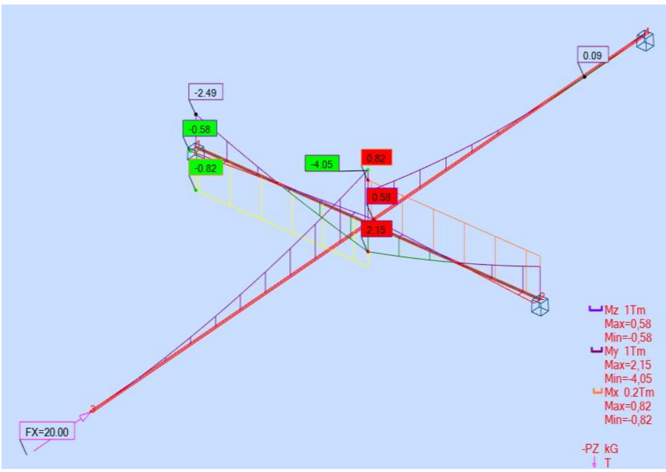


**Fig. 5.** Diagram of moments in bars without CFRP reinforcement

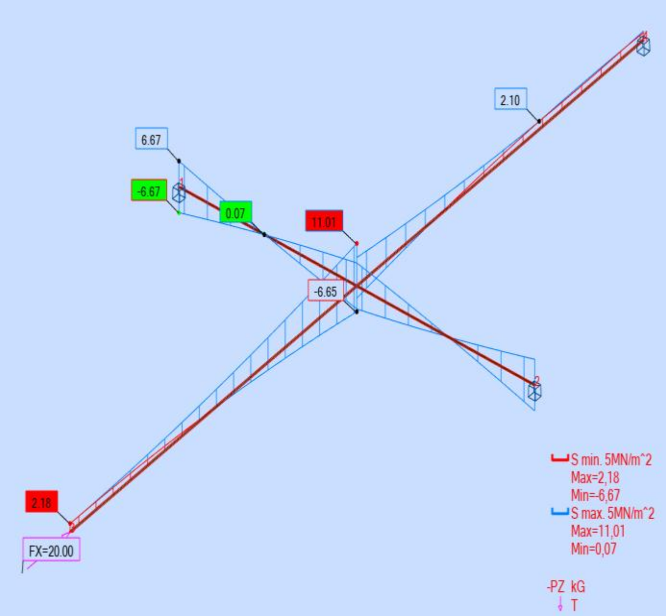


**Fig. 6.** Diagram of stresses in bars without CFRP reinforcement

### IV.III Node modelling with reinforcement

The material used in the reinforcement of the node is CFRP (Carbon Fiber Reinforced Polymer) whose characteristics are as follows [9; 10; 11; 12; 13; 14]:

**Table 4.** SikaWrap-230 C Product Characteristics [6]

| | |
|---|---|
| Elasticity module $\boldsymbol{Ef}$ | **225 000** $\boldsymbol{MPa}$ |
| Calculation lengthening $\boldsymbol{\varepsilon fud}$ | 0,60% |
| Thickness $\boldsymbol{tf}$ | 0,129 $mm$ |
| Poisson coefficient | 0,3 |
| Volumic mass | 1,75 T/m3 |

We chose to model CFRP tissue with centrally located plates in the RC bars to ensure the cohesion of the two materials; the plate / bar interaction could be further investigated later.

Figure 7 below shows the model adopted for the reinforcement of the RC bars constituting the studied node, by CFRP plates whose characteristics are those mentioned in Tab 4, these plates will be meshed in finite elements for reflect the actual behavior of this type of material.

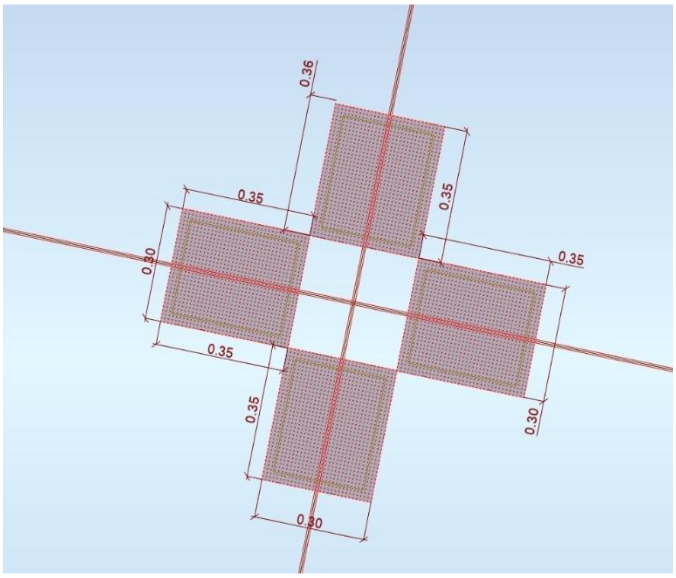


**Fig. 7.** The junction of CFRP panels (30x35 cm²) with column and beam constituting the Node

We present below the results of the stresses mentioned previously in the node without reinforcement but this time with the reinforcement modeled with the characteristics quoted in table 4.

The results of the efforts and moments remain the same since the horizontal force applied to the node does not change.

**Table 5.** Stresses in bars with CFRP reinforcement

| Effort applied to the node | Bar / Node | S max [MPa] | S min [MPa] | Fx/Ax [MPa] |
|---|---|---|---|---|
| 20 T | Column/01 | 6,79 | -6,77 | 0,01 |
| | Column /02 | 6,79 | -6,77 | 0,01 |
| | Beam/03 | 1,63 | 1,63 | 1,63 |
| | Beam/04 | 1,79 | 1,33 | 1,56 |
| 40 T | Column /01 | 8,14 | -8,1 | 0,02 |
| | Column /02 | 8,14 | -8,1 | 0,02 |
| | Beam/03 | 3,81 | 3,81 | 3,81 |
| | Beam /04 | 3,88 | 3,42 | 3,65 |
| 60 T | Column /01 | 9,5 | -9,42 | 0,04 |
| | Column /02 | 9,5 | -9,42 | 0,04 |
| | Beam /03 | 5,99 | 5,99 | 5,99 |
| | Beam /04 | 5,97 | 5,51 | 5,74 |

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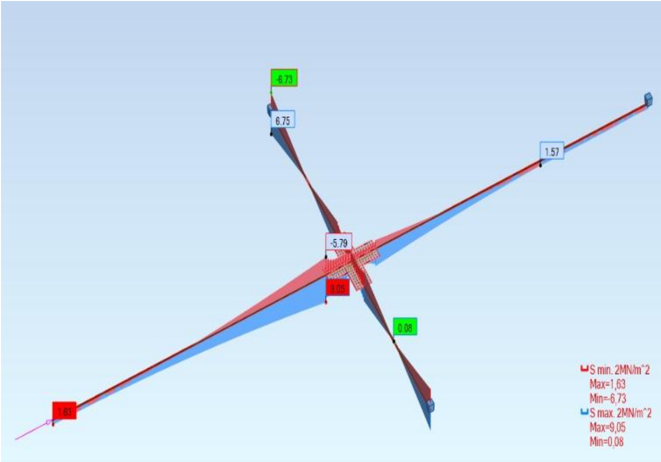


**Fig. 8.** Diagram of stresses in the bars with a reinforcement in CFRP for a horizontal effort of 20 T

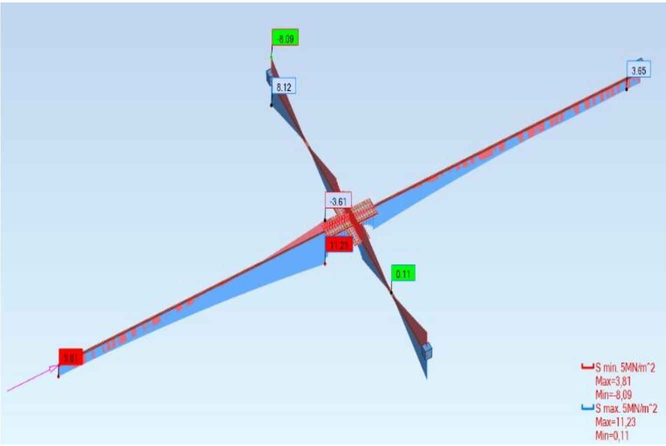


**Fig. 9.** Diagram of stresses in the bars with a reinforcement in CFRP for a horizontal effort of 40 T

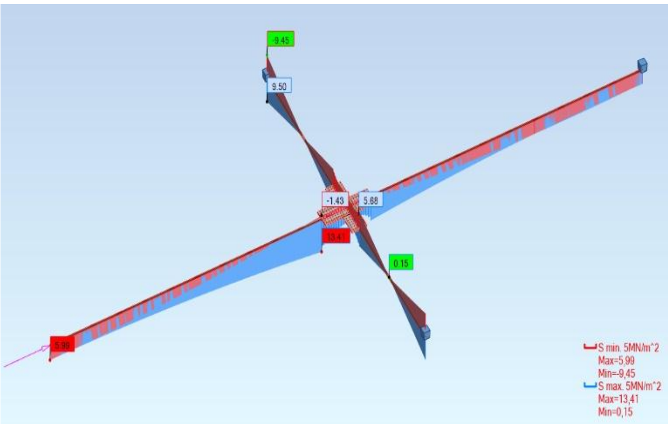


**Fig. 10.** Diagram of stresses in the bars with a reinforcement in CFRP for a horizontal effort of 60 T

## V. COMPARISON

We therefore find that there is a small reduction in the stresses in the bars as a result of the addition of CFRP reinforcements modelled by the hypothesis of adhesion in the software.

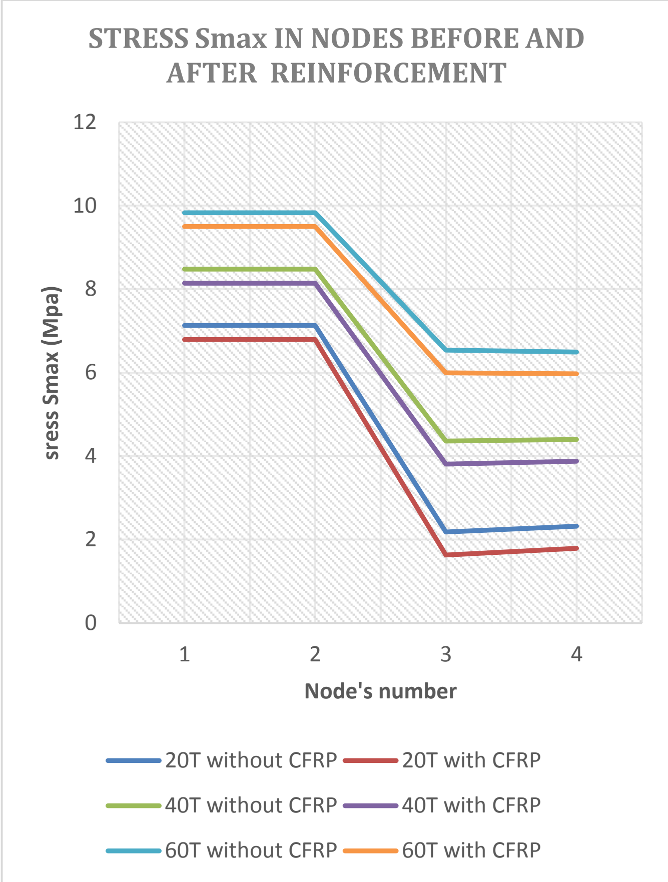


**Fig. 11.** $S_{max}$ stress values in the node before and after reinforcement, depending on the loading applied 20,40 and 60T

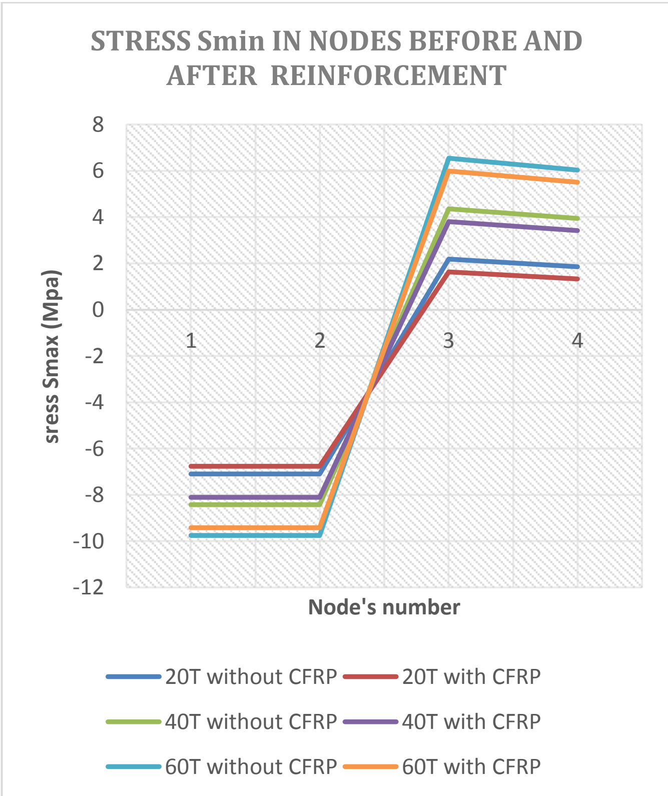


**Fig. 12.** $S_{min}$ stress values in the node before and after reinforcement, depending on the loading applied 20,40 and 60T

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Figures 11 and 12 show the decrease due to the strengthening of the node by the CFRP as shown in the table 6 below.

**Table 6.** Comparison of constraints before and after reinforcement

| Effort applied to the node | Bar / Node | Smin before reinforcement [MPa] | Smin after reinforcement [MPa] | % of reduction of stress |
|---|---|---|---|---|
| 20 T | Column/01 | -7,1 | -6,77 | 4,65% |
| | Column/02 | -7,1 | -6,77 | 4,65% |
| | Beam/03 | 2,18 | 1,63 | 25,23% |
| | Beam/04 | 1,86 | 1,33 | 28,49% |
| | | | | |
| 40 T | Column/01 | -8,43 | -8,1 | 3,91% |
| | Column/02 | -8,43 | -8,1 | 3,91% |
| | Beam/03 | 4,36 | 3,81 | 12,61% |
| | Beam/04 | 3,94 | 3,42 | 13,20% |
| | | | | |
| 60 T | Column/01 | -9,75 | -9,42 | 3,38% |
| | Column/02 | -9,75 | -9,42 | 3,38% |
| | Beam/03 | 6,54 | 5,99 | 8,41% |
| | Beam/04 | 6,03 | 5,51 | 8,62% |

the reduction of stresses with a single ply remains very negligible

that's why we're going to increase the number of plies in the digital model by increasing the thickness of the tissue of CFRP.

For a fixed horizontal force (60 T in this case) we will compare the evolution of the tensile stresses in the different bars composing the node object of study, according to the increase in the number of folds of the tissue in CFRP.

The compression stresses in the beams are admissible, therefore we will focus on the tensile stresses in the columns.

the table 7 below shows the increase in the percentage of stress reduction by increasing the number of folds of the tissue

the reduction of tensile stresses can reach 17% in our case, something which presents a significant or even important reduction and this reaching a maximum number of plies (in this case 5 plies) to ensure a certain adhesion between the different layers of tissue of CFRP.

**Table 7.** Constraints before and after reinforcement depending on the number of plies of the CFRP, for a horizontal force of 60T

| Folds Number | Bar / Node | S min before reinforcement [MPa] | S min after reinforcement [MPa] | % of reduction of stress |
|---|---|---|---|---|
| 1 | Column/01 | -9,75 | -9,42 | 3,38% |
| | Column/02 | -9,75 | -9,42 | 3,38% |
| 2 | Column/01 | -9,75 | -9,09 | 6,77% |
| | Column/02 | -9,75 | -9,09 | 6,77% |
| 3 | Column/01 | -9,75 | -8,76 | 10,15% |
| | Column/02 | -9,75 | -8,76 | 10,15% |
| 4 | Column/01 | -9,75 | -8,43 | 13,54% |
| | Column/02 | -9,75 | -8,43 | 13,54% |
| 5 | Column/01 | -9,75 | -8,1 | 16,92% |
| | Column/02 | -9,75 | -8,1 | 16,92% |

thus, by modeling the tissue of CFRP glued to the node RC and by applying the equation found in the paragraph III.II, we can conclude the necessary thickness of the tissue to absorb the stresses due to the seismic demands of the studied node.

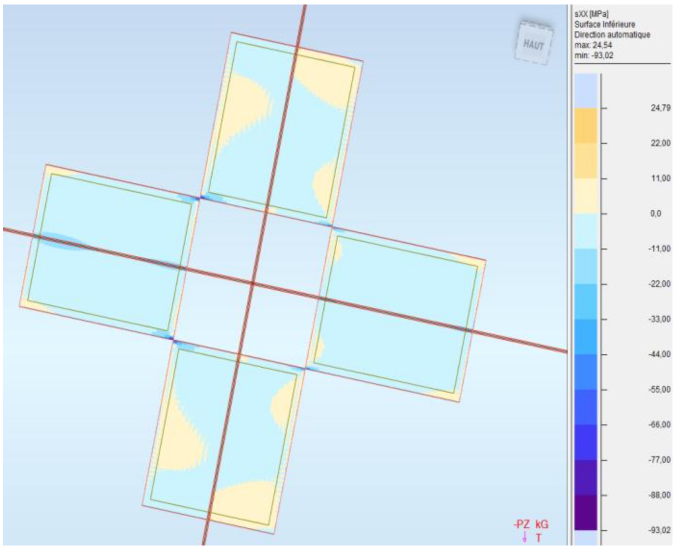


**Fig. 13.** Distribution of the Sxx stress in the CFRP tissue

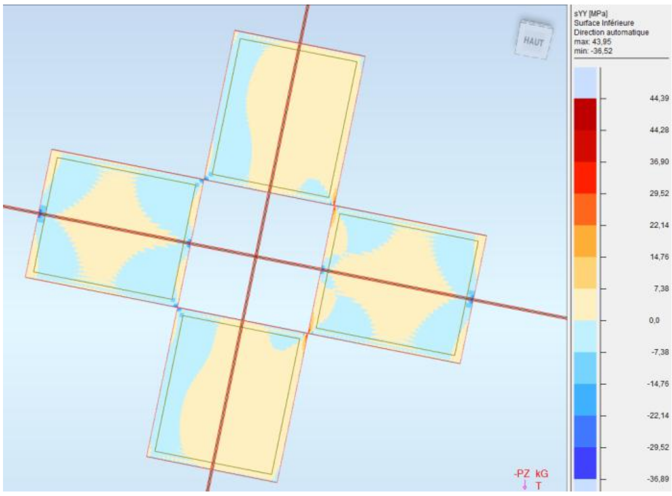

**Fig. 14.** Distribution of the Syy stress in the CFRP tissue

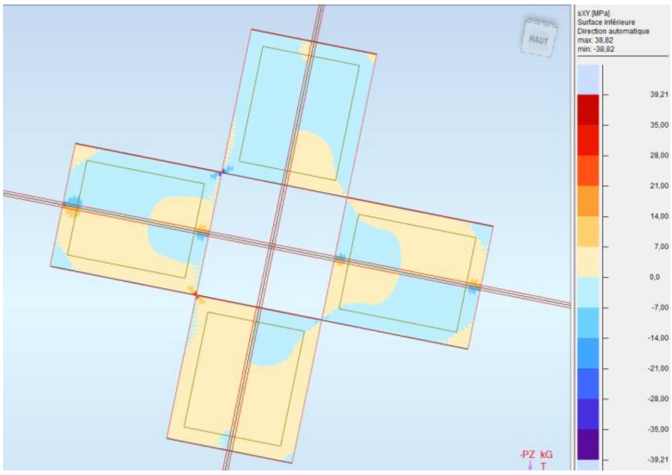

**Fig. 15.** Distribution of the Sxy stress in the CFRP tissue

The distribution of stresses in the CFRP tissue clearly shows the participation of the tissue in the absorption of the horizontal force applied to the node, hence the decrease in the stress on the elements constituting nodes (column and beam), hence the use of this reinforcement method for the seismic reinforcement of existing buildings.

## V. CONCLUSION AND DISCUSSION

As shown by the modeling carried out in this paper, we can say that the seismic stresses in the elements of reinforced concrete subjected to horizontal forces can be diminished by an adequate reinforcement of bonded tissue of CFRP on the considered element.

The number of folds required to achieve the confinement stress required by seismic regulation has been discussed in Section III.II.

The engineer faced with finding seismic leveling solutions of an old building constructed before the onset of seismic regulations can use the formula mentioned above to calculate the number of folds required to reach the confinement stress, then model the structure by adding the reinforcement in the nodes and increasing their thicknesses according to the number of folds found in the equation, and thus to note the very considerable reduction of the stresses in the reinforced nodes object of study.

Nevertheless, certain conditions must be respected namely: the respect of a maximum number of folds required by the supplier to avoid the problem of detachment of the tissue, and the respect of the flocking of the tissue for an eventual protection against fire.

The tensile stresses obtained after reinforcement remain unacceptable, these CFRP fabrics from SikaWrap-230 C are not enough to absorb the horizontal seismic stress.

However, we can achieve a greater level of stress reduction by choosing other tissues with more efficient characteristics such as SikaWrap-600 C

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