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INFLUENCE OF COMPOSITE REINFORCEMENT ON THE DELOCALIZATION OF PLASTIC HINGES

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Abstract

Following multiple earthquakes in Algeria, large numbers of reinforced concrete structures have been severely damaged or destroyed, making it necessary to evaluate the actual seismic behavior of existing buildings. Classic linear elastic methods do not accurately represent the actual behavior of the structure, which makes it necessary to use calculation methods that take into account the post-elastic domain of the structure. The Push over method is a procedure that correctly predicts dynamic behavior in the event of a future earthquake. For frame structures, the formation of plastic hinges in the columns results in the transformation of the structure into a mechanism. This explains the need to give the post a higher strength than the beams.

Keywords: Earthquake, Existing building, Push over, Plastic hinges, delocalization, Reinforcement, composite materials, CFRP, GFRP, Capacity curve.

الخلاصة: نظرا للزلازل التي ضربت الجزائر، تعرضت أعداد كبيرة من الهياكل الخرسانية المسلحة لأضرار بالغة أو مدمرة، مما جعل من الضروري تقييم السلوك الزلزالي الفعلي للمباني القائمة. لا تمثل الأساليب الكلاسيكية الخطية المرنة بدقة السلوك الفعلي للمبنى، مما يجعل من الضروري استخدام أساليب حساب تأخذ بعين الاعتبار مجال ما بعد المرونة للهيكل.

طريقة الدفع(Push over) هو إجراء يتوقع السلوك الديناميكي بشكل صحيح في حالة وقوع زلزال في المستقبل. بالنسبة لهياكل يؤدي تكوين مفصلات بلاستيكية في الأعمدة إلى تحويل الهيكل إلى آلية. وهذا يفسر الحاجة إلى منح الاعمدة قوة أعلى من الروافد.

في هذا العمل، تم تنفيذ نموذج غير خطي للمبنى القائم المكون من خمسة مستويات بواسطة برنامج **SAP2000 V14**. وبعد الدراسة والتحليل، اقترحنا تقنيتان لتعزيز الأعمدة باستخدام مواد مركبة تستند إلى الكربون **"CFRP"** وتستند إلى الزجاج **"GFRP"**. تظهر النتائج تأثير المواد المركبة على قوة المبنى وعلى إزالة مفاصل البلاستيك من الأعمدة نحو الروافد.

1. INTRODUCTION

A risk is the consequence of an event of a certain magnitude with a certain probability of occurrence (hazard). It may be natural or human in origin. The effects can endanger a large number of people, cause significant damage and exceed the response capacity of the directly affected bodies. The transition from risk to risk presupposes the consideration of the vulnerability of the issues subject to that risk [1].

The seismic risk is therefore the combination of the seismic hazard at a given point and the vulnerability of the issues exposed to it (people, buildings, infrastructure...). The extent of the damage suffered thus depends very strongly on the vulnerability of the stakes to this hazard. While it is impossible to take action to limit the scale or occurrence of earthquakes, it is possible to increase the resilience of the challenges at stake: this is the objective of earthquake regulation [2], [3].

Seismic vulnerability is defined by the degree of damage for different events. Vulnerability depends on the physical and geometric characteristics of the buildings. The vulnerability of existing buildings requires structural rehabilitation and is of particular importance and urgency when applied to the upgrading of seismic standards [4].

The reinforcement of a structure is part of rehabilitation, this method involves expensive renovations which can be envisaged in a voluntary approach and it serves to remedy and/or reduce the vulnerability of nonearthquake or new buildings; there are some reinforcement techniques among them, reinforcement with composite materials [6].

In the context of this work, the following concerns are addressed:

- Assessment of the seismic vulnerability of an existing building constructed prior to the application of seismic regulations.
- Does the building under study require reinforcement?
- What are the reinforcement techniques to choose in our work and where to opt for reinforcement?

Have we managed to satisfy the various demands of the existing building in the face of future earthquakes?

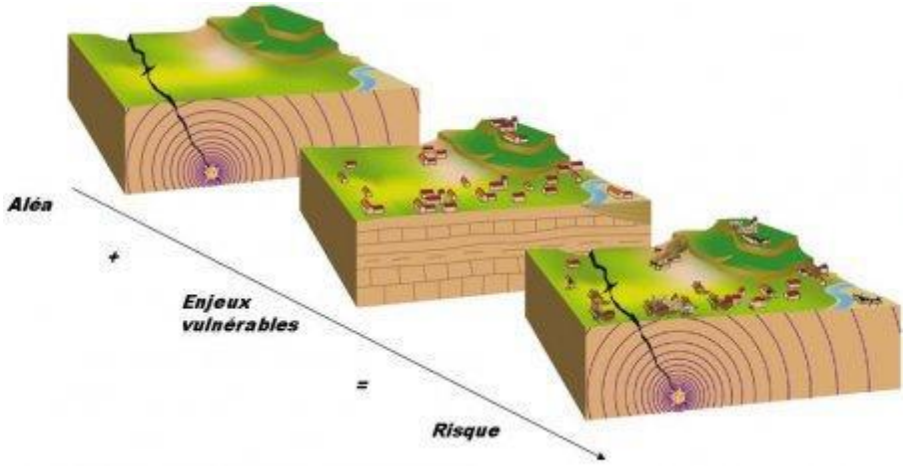


Figure 1 Seismic Hazard

2. OBJECTIVE REHABILITATION

Relates to repair or reinforcement operations, the repair is intended to restore the original performance of a damaged structure, while reinforcement is intended to improve the performance of a structure, damaged or not, to meet new needs or to meet a need for conformity. Of course, after a repair operation, the structure may perform better than it did at the beginning. The objectives of seismic reinforcement can be of different kinds: to increase the resistance to lateral forces, to increase the ductility, or to combine these two aspects, in order to meet the new requirements of resistance to earthquakes and mainly to save a maximum of lives for a tremor associated with a certain seismic hazard (and especially with a certain return period) [5].

3. STRENGTHENING

Reinforcement is an operation that consists in increasing the service level (ductility, strength) of construction to allow it to be used under conditions not originally intended or to provide it with sufficient protection against stresses that were not taken into account in the calculations [1].

3.1. Strengthening strategies:

Two global strategies can be envisaged for carrying out seismic rehabilitation:

- Reduce the level of seismic loads to which the structure could be exposed and improve the performance level of the structure.
- An earthquake generates displacement imposed on the sitting floor: the structure oscillates and moves it’s mass. Thus, in order to minimize the level of the seismic load to which the structure will be exposed, it is possible to reduce the various masses (replace the floor, the metal framework, etc.), reduce the period of the structure to avoid entering into resonance with the soil or add elements of parasismic isolation.[1]

On the other hand, in order to improve the performance of the work, it is possible to:

- increase strength
- Increase the ductility;
- Modify the stiffness;
- Increase the damping.

4. COMPOSITE MATERIALS

4.1. Definition:

The composite material may be defined in general as the assembly of two or more materials, the final assembly having properties superior to the properties of each of the constituent materials. Arrangements of fibers are now generally referred to as “composite materials”, the reinforcements which are immersed in a matrix whose mechanical strength is much lower. The matrix ensures the cohesion and orientation of the fibers; it also makes it possible to transmit the loads to which the parts are exposed [12].

We need to differentiate between loads and reinforcements. The fillers, in the form of fragmentary elements, powders or liquids, modify a property of the material to which it is added (for example the resistance to shocks, UV resistance, fire behavior, etc.). The reinforcements, in the form of fibers, only contribute to improving the mechanical strength and the rigidity of the part in which they are incorporated. [12]

4.2. Advantages and disadvantages of the use of composite materials

4.2.1. Advantage:

- Ease of formatting
- Lightness:
- Adaptability:
- Resistance to corrosion or oxidation of waste:
- Electrical and thermal insulation:

4.2.2. Disadvantages:

While the benefits of composite materials are impressive, they are not a silver bullet for all applications. Disadvantages or problems exist and may prevent their use. The most common drawbacks are the following [13]:

- Cost
- Design and Analysis
- Assembly:
- Damage tolerance

4.2.3 Classifications of composite materials:

Composite materials can be classified according to the shape of the components or according to the nature of the components [13].

Classification according to the form of constituents:

Depending on the shape of the constituents, composites are classified into two major classes (particle composites and fiber composites).

A. Fiber composites

B. Particule composites

Classification according to the nature of the constituents:

1. Organic matrix composites (resin, fillers), with:
    - Mineral fibers: glass, carbon, etc.
    - Organic fibers: Kevlar, polyamides, etc.
    - Metal fibers: boron, aluminum, etc.
2. Metal matrix composites (light and ultra-light aluminum, magnesium and titanium alloys), with:
    - Mineral fibers: carbon, silicon carbide (SiC),
    - Metal fibers: boron,
    - Metallic-mineral fibers: boron fibers coated with silicon carbide (BorSiC).
3. Mineral matrix (ceramic) composites, with:
    - Metal fibers: boron,
    - Metallic particles: cermet’s,
    - Mineral particles: fuel, nitrides, etc.

5. FIBER REINFORCED COMPOSITE MATERIALS (FRP)

5.1. Fiber-reinforced composite materials (FRP):

Composite materials composed of fibers polymers reinforced “FRP” are synthetic products consisting mainly of fiber reinforcements, supported by a binder called a matrix. Their behavior depends mainly on the percentage of fibers and the mechanical properties of the constituents. It is the fibers reinforcements that give the composites their constituents. Highly directional, imposing on them an anisotropic and essentially linear elastic behavior until rupture [12].

Over the past two decades, the use of fiber-reinforced polymer has increased significantly in the civil engineering community. The favorable intrinsic properties possessed by its materials (high strength/weight; good behavior/corrosion; electromagnetic neutrality...) can be exploited to increase the strength and/or rehabilitation of concrete, masonry and wood constructions. FRP has become a basis for strengthening techniques, and rehabilitation is also increasingly economically competitive. [11]

Figure 2 Reinforcing Slabs, Beams, and Columns [14]

Figure 3 Reinforcement of joints [14]

6. MODELING AN EXISTING REINFORCED CONCRETE BUILDING

The building subject of this study was one of the buildings most damaged during the Boumerdes earthquake (May 2003) due to the lack of lateral stability, the 5-level (GF+4) reinforced concrete building for residential use, located in Oran (classified in zone IIa according to RPA 99 version2003) [4].

The modelling of the building is carried out in two phases, using SAP2000 version 14, the 1st phase is carried out a linear elastic analysis and the 2nd phase is carried out a non-linear analysis push over.

6.1. Description of the characteristics of the building:

6.1.1. Geometric characteristics (see plan below)

Table 1 Geometric characteristics of the building

Geometric characteristics	
Total length of the building	22.00m
Total width of the building	17.00m
Total height of the building	16.50m (acroteric height 50cm)

Height of current floors	3.00m
RDC Height	4.00m

6.1.2. Material characteristics:

Table 2 Mechanical Characteristics of the Building

Materials	**Module of elasticity (E) [MPa]**	**Density(ρ) [Ton/m^3]**	**Poisson ratio (η)**	**[MPa]**	
Concrete	$3,22,10^4$	2.5	0.2	$\mathbf{f_{c28}}$	25
				f_{tj}	2.1
Steel	$2.1\ 10^5$	0,8004	0.3	**Nuance**	FeE 400
					FeE 235

6.1.3 View of the reinforced concrete building (R+4):

Figures (Figure 4) (Figure 5) show the plan view and 3D view of the existing building respectively

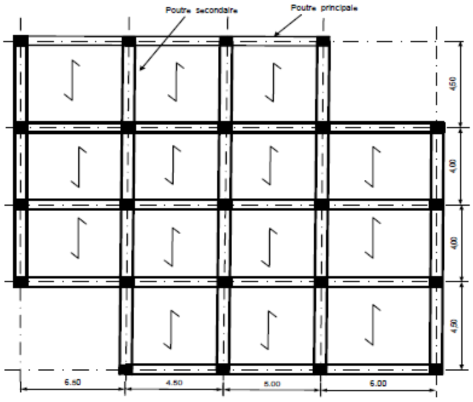


Figure 4 Plan view of the existing building

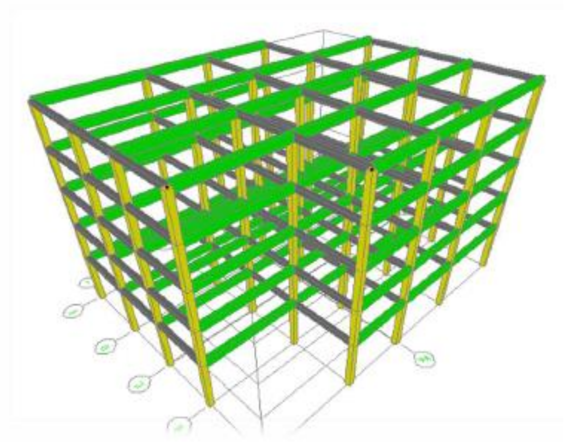


Figure 5 3D view of the existing building

7. DAMAGE LEVELS

FEMA Regulation 356 [18] defines three points to define the state of degradation of each element and thus its degree of penetration into the plastic domain.

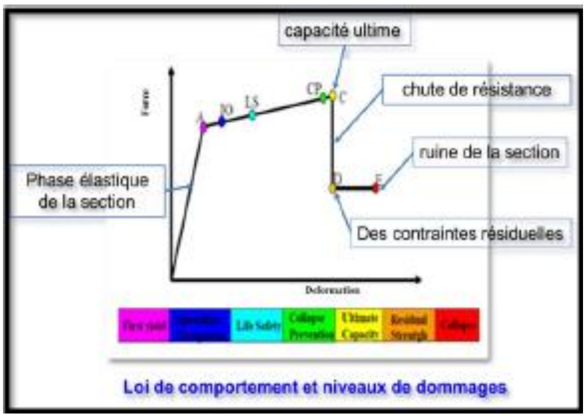


Figure 6 Behavioral Law and Damage Levels

FEMA 356 proposes three levels to define the damage status of each section:

- **Immediate occupancy "IO":** The first level of damage (minimal damage) corresponds to a level of performance of the structure.

- **Life safety "LS":** The second level of damage (repairable damage) corresponds to the level of performance of the structure.
- **Collapse prevention (CP):** The third level of damage (significant damage) corresponds to the level of performance of the structure. [14], [18].

8. NON-LINEAR RESULTS OF THE EXISTING BUILDING 1

8.1. Capacity curve:

The curves are shown in FIG. 7 give the resistance capacities as a function of the displacements of the existing building 1.

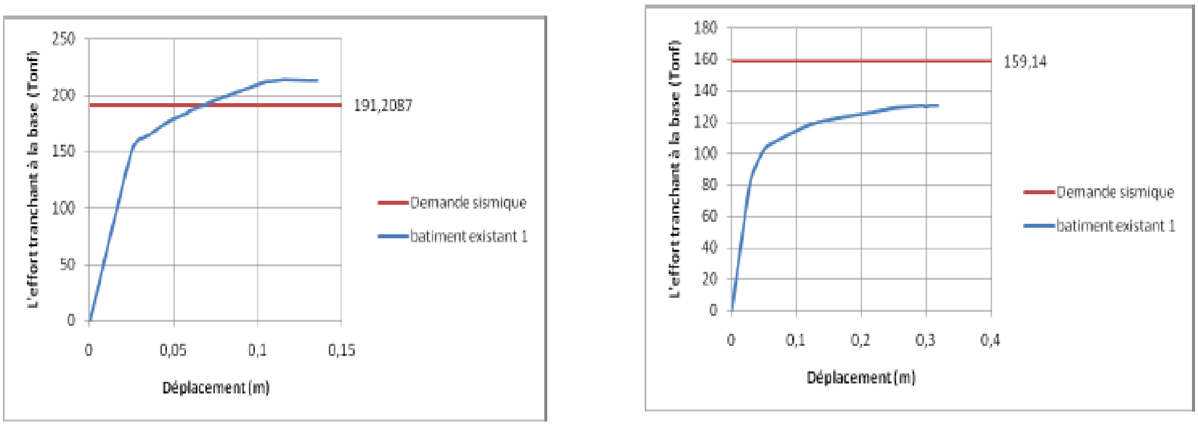


Figure 7 Maximum capacity of the building in direction (x) and (y)

It can be seen that the maximum capacity in direction (x) is greater than the seismic demand of the difference of 10.21% and in direction (y) it is less than the seismic demand of a difference of 22.30%.

8.2 Plastic hinges:

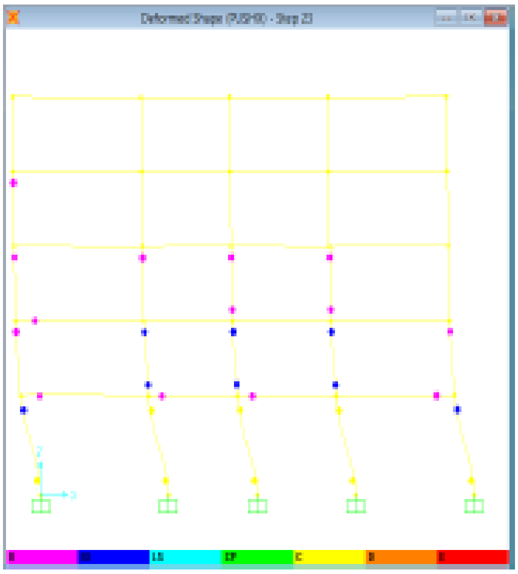


Figure 8 Plastic Hinges (x direction)

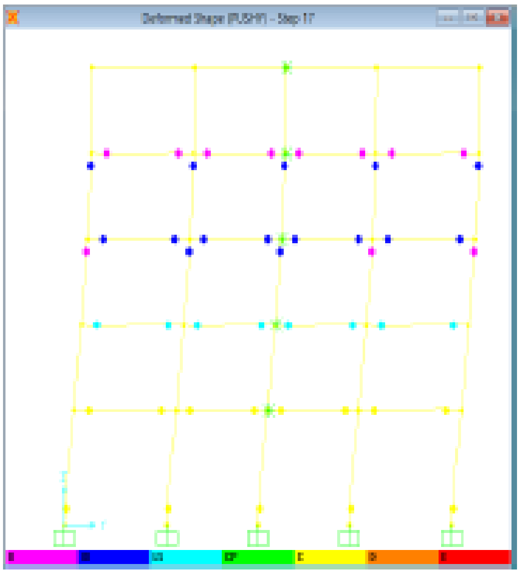


Figure 9 Plastic Hinges (y direction)

After visualization of the plastic hinges, it is noted that the mechanism developed is a mixed mechanism in the two directions (x) and (y) since the hinges were formed simultaneously in the beams and the columns.

The damage levels in the (x) direction indicate that the hinges formed in the beams are of the (B) type, whereas for the columns, at the 2nd-floor levels, the developed hinges are of the B story and in the 1st story they are of the B-IO type, whereas at the ground level, the plastic hinges are of the IO-C story. In the direction (y) concerning the 3rd ^{s}tory, the plastic hinges are of type B at the level of the beams I, for the columns are in story IO; in the 2nd story, the developed hinges are of type IO at the level of the beams and formation of the ball joints of type B-IO at the level of the columns, in the 1st sto^{ry} the hinges are formed only at the levels of the beams of type LS and in the ground floor the hinges are of type C at the level of the beams and at the bottom of the columns.

Based on the results found, it was noted that the building studied is considered vulnerable for the following reasons:

- The resilience capacity of these buildings is significantly lower than the seismic demand in the y direction;
- The dimensions of the beams are greater than that of the columns (the phenomenon of weak columns - strong beams) in the existing building 1.
- Insufficient lateral stability of buildings (ht=16.5m>14m sails must be fitted) **[5].**
- The level of damage for certain elements, in particular in the "V" frames, is significant.

As a result of the results found, the existing building is vulnerable due to several problems including non-compliance with the principle of strong poles/weak beams, flexible CPR and lack of lateral stability, so it requires reinforcement and among the reinforcement techniques cited in Chapter I the reinforcement by FRP composite materials using two types CFRP and GFRP have been chosen [8].

Composite materials, owing to their high mechanical characteristics and their low weights, their very good corrosion performance, and their mold ability, are particularly advantageous materials for filling civil engineering structures [10].

9. STRENGTHENING BY COMPOSITE MATERIALS

The composite material FRP (Fiber Reinforced Polymer) based on carbon (CFRP) and glass (GFRP) was used with a thickness of 1 mm which has the following characteristics [9]:

Table 3: CFRP and GFRP characteristics

Material Type	Potency coefficient (Υ)	Modulus of elasticity (E) [MPa]	Shear modulus (G) [MPa]
CFRP	Υ_{xy}=0.22 Υ_{xz}=0.22 Υ_{yz}=0.30	E_x=240000 E_y=19000 E_z=19000	G_{xy}=12500 G_{xz}=12500 G_{yz}=7500
GFRP	Υ_{xy}=0.216 Υ_{xz}=0.216 Υ_{yz}=0.3	E_x=20680 E_y=6895 E_z=6895	G_{xy}=1517 G_{xz}=1517 G_{yz}=2654

The strengthening is applied to the gantry (V) on the 03 middle columns because the degree of damage is high in these columns (formulation of type C plastic hinges and inclination of the ground floor).

9.1. Strengthening by CFRP

9.1.1. Existing building (1):

Position of composite materials

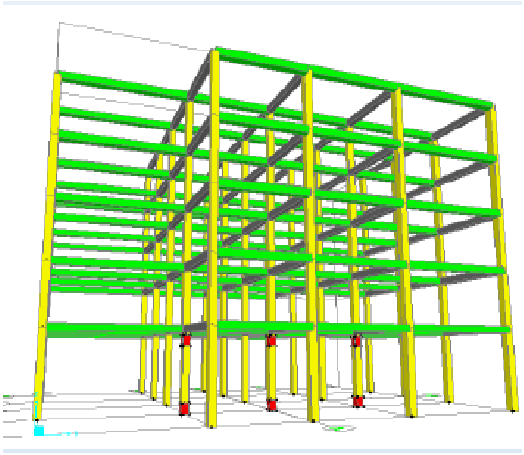


Figure 10 Variant 1

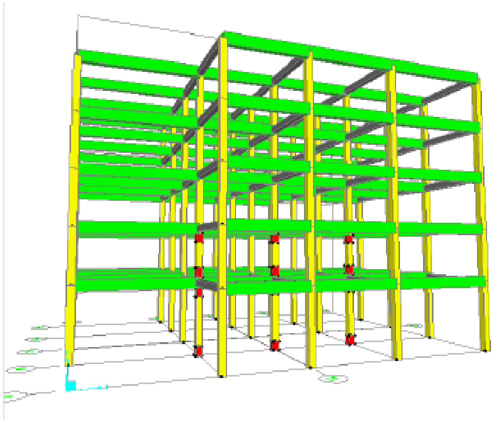


Figure 11 Variant 2

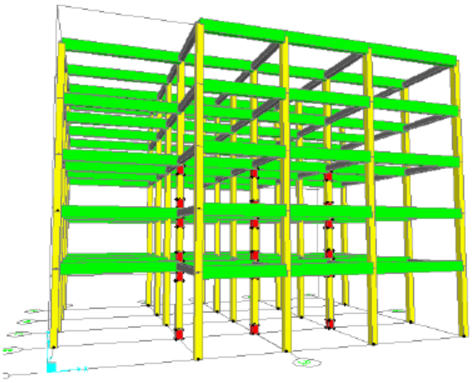


Figure 12 Variant 3

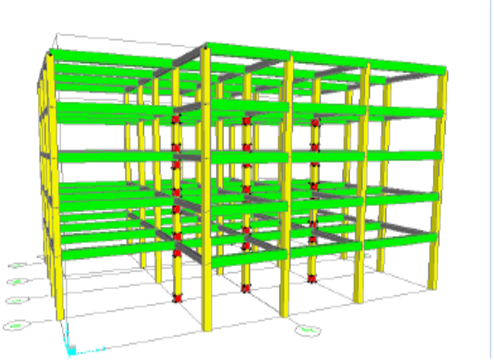


Figure 13 Variant 4

9.1.2. Capacity curves:

In the direction x) (Figure 14), **it** was found that the shear force at the base increased from 191,612 T for variant (3) to 168,295 T for variant (4), i.e. a decrease of 12.16%, and in direction (y) (Figure 14), the shear force increased from 159,291 T to 159,856 T, i.e. an increase of 0.35%.

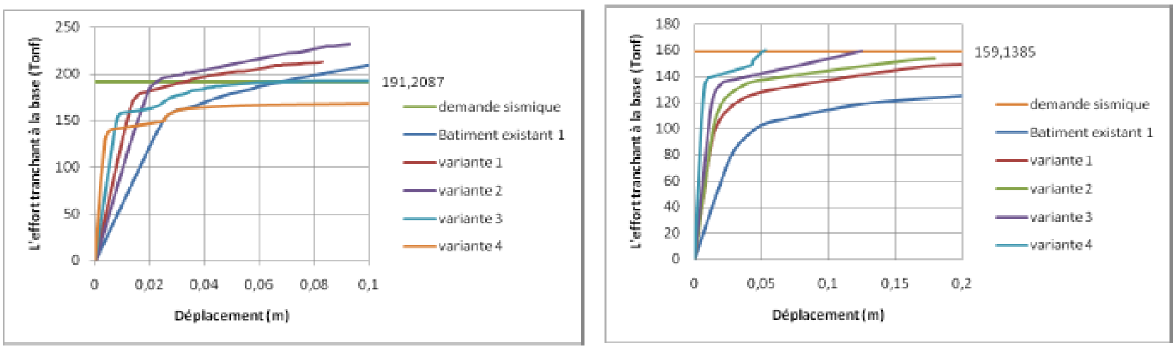


Figure14 Push over Curve in Direction (x) and (y)

9.1.3. Comparing the results of the different variants:
a) Period:

Table 4 Summary table of periods

The level	Existing	Variant 1	Variant 2	Variant 3	Variant 4
Period(s)	*1,44408*	*1,10172*	*0,85134*	*0,61311*	*0,38142*

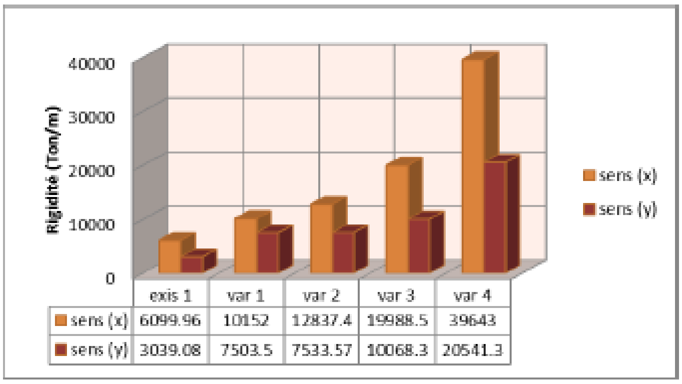
It can be concluded that, after each strengthening, a decrease of 28.05% in the building's proper period

Table 5 Push over Analysis Results

		elastic limit state			Ultimate State	
		V_y [Tone]	d_y [m]	K_y [Ton/m]	V_u [Tone]	d_u [m]
Direction (x)	**Existing**	127,1658	0.020847	6099,957	212,9708	0,13518
	Variant 1	120,6664	0.012477	10151,992	232,0003	0.093015
	Variant 2	130,7236	0.10183	12837,435	212,7256	0,0828
	Variant 3	103,8405	0.005195	19988,547	191,6119	1,07447
	Variant 4	79,20670	0.001998	39642,992	168,2951	0,63995
Direction (y)	**Existing**	52,5760	0,017	3039,075	130,113	0,31739
	Variant 1	53,1291	0.00708	7503,504	149,350	0,21357
	Variant 2	66,3181	0.008803	7533,583	153,928	0,17948
	Variant 3	76/4892	0.007587	10068,343	159,291	0.12490
	Variant 4	104,3702	0.005081	20541,271	159,856	0,05263

b) Stiffness:

Concerning stiffness, it has been noted that in the direction (x) it increased after the change from one variant to another, of the order of 36.54% after the change from the existing building to variant (4), and in the direction (y) there was an increase of 34.01%, which implies that the strengthening by CFRP had an influence on stiffness.

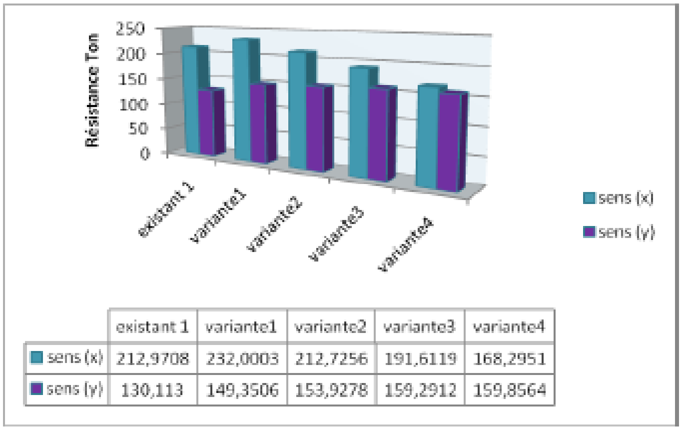


	exis 1	var 1	var 2	var 3	var 4
sens (x)	6099.96	10152	12837.4	19988.5	39643
sens (y)	3039.08	7503.5	7533.57	10068.3	20541.3

Figure15 Initial stiffness of the different variants

(c) Strength:

On the subject of strength, it was known that it increased by 8.2% after the strengthening of the ground floor and then it decreased by 9.92% in passing from one variant to another in the direction (x) on the other hand in the direction y it was found that it increased by the order of 4.89%.



	existant 1	variante1	variante2	variante3	variante4
sens (x)	212,9708	232,0003	212,7256	191,6119	168,2951
sens (y)	130,113	149,3506	153,9278	159,2912	159,8564

Figure 16 Strength capacity of different variants

d) Plastic hinges:

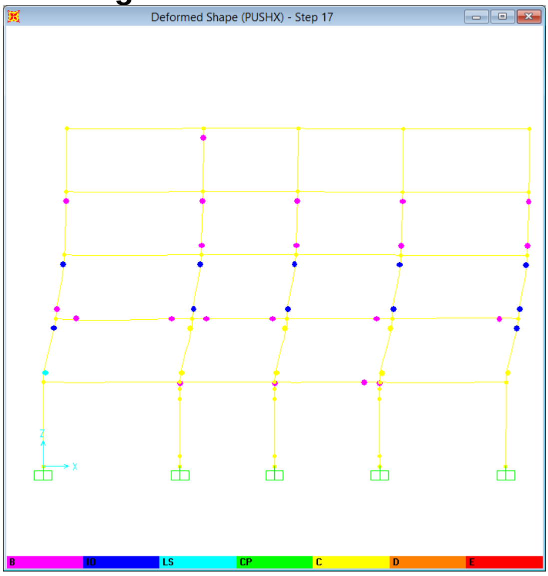


Figure 17 Variant 1

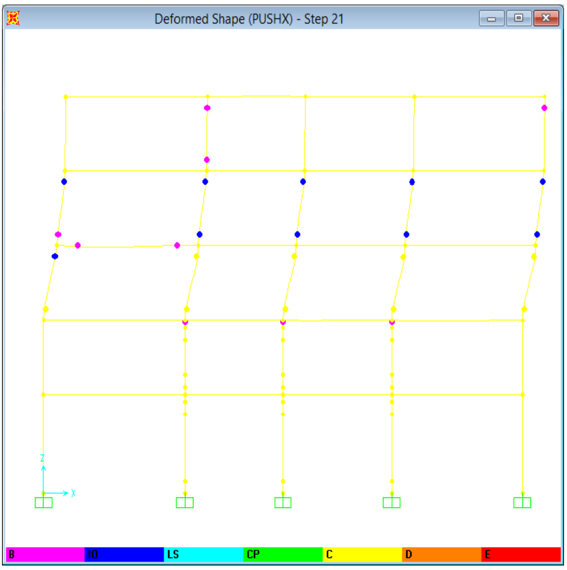


Figure 18 Variant 2

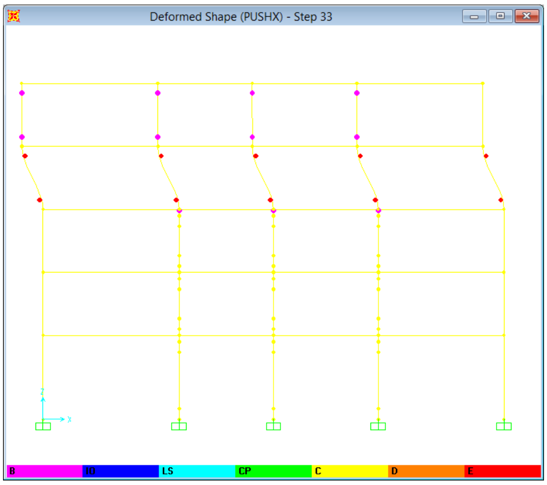


Figure 19 Variant 3

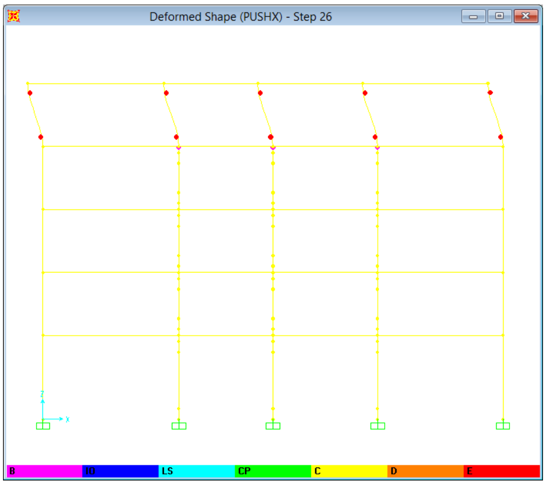


Figure 20 Variant 4

Following the result found from the push over analysis, it is found that in the direction (x) at the level of the beams, the delocalization of the type B-ball joints from the GF to the 1st story and at the level of the columns, the formation of the new ball joints at the level of the reinforced story (GF) nodes of type B, then the delocalization of the GF ball joints to the 1st story with the same degree of damage and, at the 2nd story, a change in the degree of damage from type B to type IO, formation of new type B ball joints in the top two floors. As regards the inclination of the story, it has been observed that after each story reinforcement, it has passed to the story which follows it.

10. STRENGTHENING BY GFRP

10.1. Capacity curves:

In the direction (x) (Figure 21)**,** it is noted that the shear force at the base increased from 198.263 T for variant (a) to 168.352 T for variant (b), i.e. a decrease of 11.05%, and in direction (y) (Figure 21), the shear force increased from 158.616 T to 166.067 T, i.e. an increase of 4.49%.

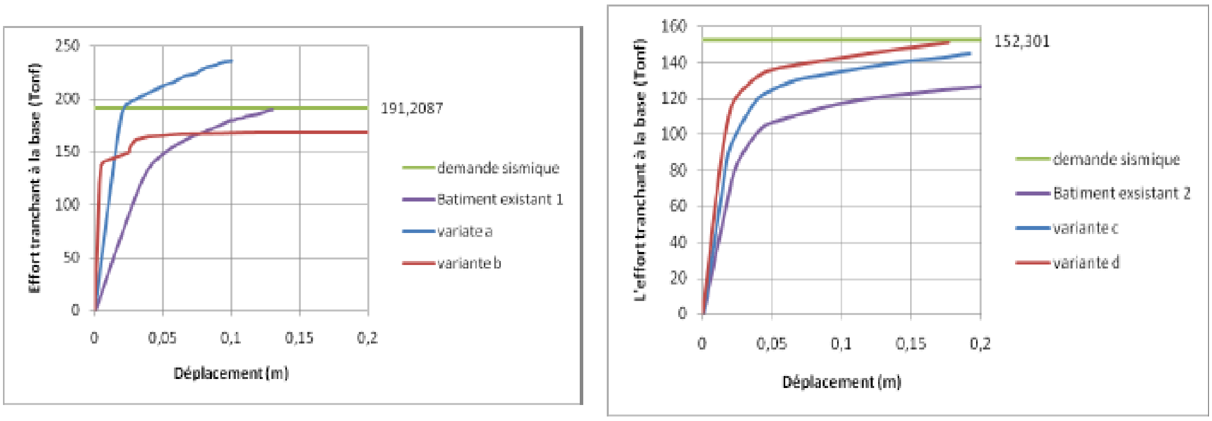


Figure21 Push Over curves in directions (x) and (y)

10.2. Plastic hinges:

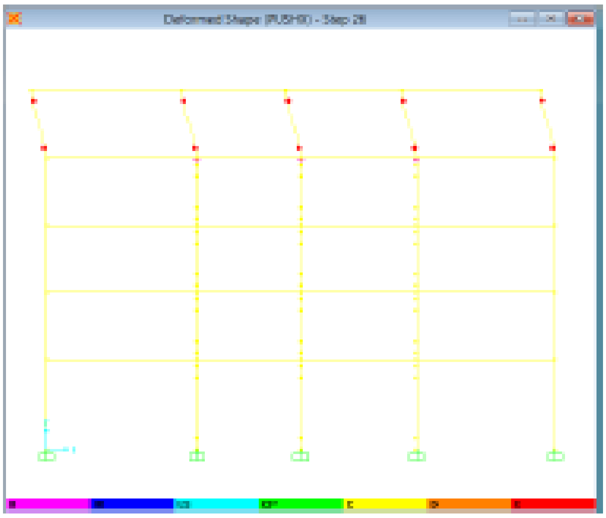


Figure22 Plastic hinges (x direction)

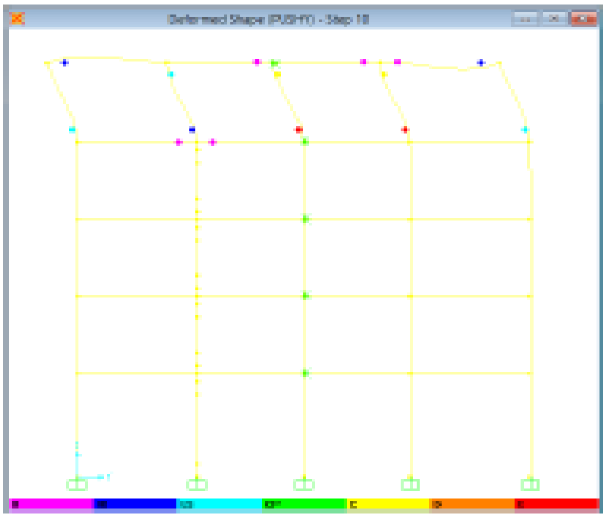


Figure**23** Plastic hinges (sense-y)

After the strengthening of the 3rd story in the (x) direction, the absence of the hinges at the beams and the delocalization of the hinges of the nodes (story B) from the 2nd story to the reinforced story and at the columns of the 4th story a change in the degree of damage of type B to E, in the (y) direction, no change in the beams of 3rd and last story (rest B) but there is a change in the degree of damage of type LS to IO-LS-C-E at the columns of the last story.

As regards the inclination of the story, it has been observed that after each reinforcement of the story, it has passed which follows it.

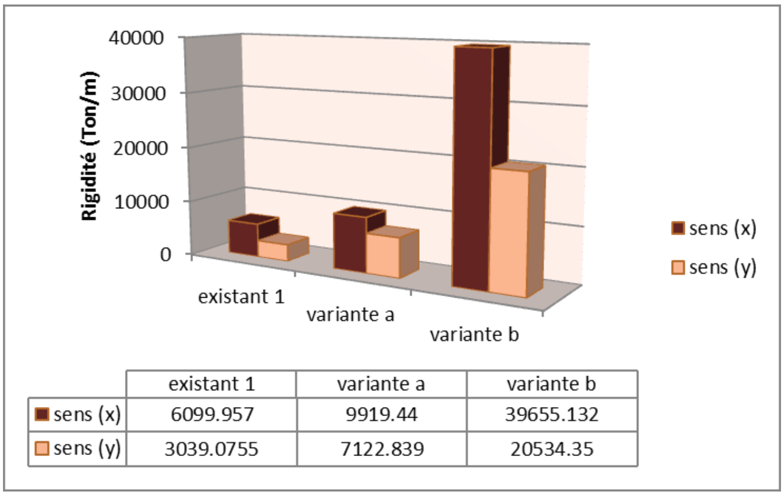
a. Comparison of results of variants:

Table 6 Push over Analysis Results

		elastic limit state			Ultimate State	
		V_y [Tone]	d_y [m]	K_y [Ton/m]	V_u [Tone]	d_u [m]
Direction (x)	**Variant a**	129,6471	0,1307	991,944	236,189	0.09988
	Variant b	79,1913	0.001997	39653,132	168,3515	0,565,448
Direction (y)	**Variant a**	53,3928	0.007496	7122,839	148,4533	0,251,822
	Variant b	104,3761	0.005083	20534.35	166,0665	0.05629

a) Stiffness:

In the (x) direction, the value of the building stiffness increases after each strengthening of a deviation of 56.75% and in the (y) direction it has been known that it has also increased of the order of 61.32%, which indicates the influence of GFRP on the stiffness.

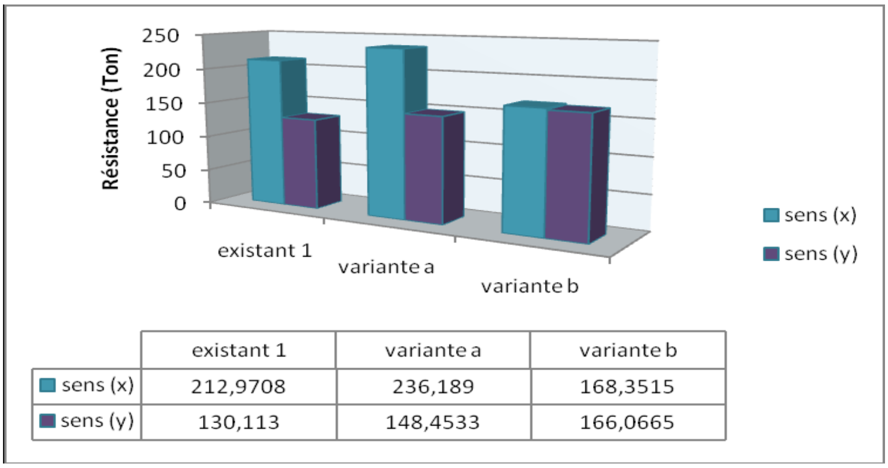


	existant 1	variante a	variante b
■ sens (x)	6099.957	9919.44	39655.132
□ sens (y)	3039.0755	7122.839	20534.35

Figure 24 Initial stiffness of the different variants

b) Strength:

As regards resistance, there is a variation from one variant to another except that it increased in the (y) direction by 11.48% and in the (x) direction it increased by 9.8% after the reinforcement of the ground floor and then it decreased by 28.72% after the reinforcement of the 3rd floor.



	existant 1	variante a	variante b
🟦 sens (x)	212,9708	236,189	168,3515
🟪 sens (y)	130,113	148,4533	166,0665

Figure 25 Resistance capacity of the different variants

11. CONCLUSION

To conclude this work, according to the results found after the strengthening by two composite materials FRP based on carbon and FRP based on glass. We have extracted the following conclusions:

- ❖ The reinforcement with the two composite materials influences the building period, we found that after each reinforcement a decrease in the period which implies the increase of the stiffness of [CFRP] and [GFRP] serves increased the stiffness;
- ❖ The two materials allow increasing the strength of the buildings with respect to their shear forces at the base which implies that they influence the strength;
- ❖ After reinforcing, a delocalization of the plastic hinges is observed in the existing (1), it is vertical to the columns because of the effect of weak columns/strong beams;
- ❖ Once the building was strengthened by CFRP or GFRP, we noticed a decrease in the lateral displacements between stories of the reinforced levels;
- ❖ After the comparison between the two strengthening materials, no great difference was found between them because of their similar characteristics.

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