Proceedings of the 9th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2024)
Chestnut Conference Centre - University of Toronto, Toronto, Canada–June13-15, 2024
Paper No. 122
DOI: 10.11159/iccste24.122

Increase in the axial resistance of concrete walls for buildings through the application of Carbon Fiber Polymers

Lenin Bendezú R.[1], Luis Santa Cruz D.[1], Elena Espinoza M.[1]
[1]Civil Engineering Department, Peruvian University of Applied Sciences
Av. Alameda San Marcos, 2, Lima, Peru
pciplben@upc.edu.pe; u20181d390@upc.edu.pe; u201512372@upc.edu.pe

Abstract- This experimental work hopes to provide a potential solution by proposing techniques to improve the axial resistance capacity of reinforced concrete walls, using high-strength carbon filaments, and proposing a practical methodology for reinforcing existing reinforced concrete columns and walls. The methodology used to improve this work consists of the exploration and experimentation of two explicit parts, the first being a progression of material tests carried out in the laboratories of the Pontificia Universidad Católica del Perú, with the purpose of determining the direct mechanical properties. and not direct. The second part of the work included the analysis of the reinforced concrete walls through the non-linear concept modeled with the finite element method, verifying the non-linear attributes of the concrete by increasing the high-resistance carbon fiber. The results found have been obtained using the Cypecad software, and show that, in the case of carbon fiber reinforced specimens, a moment of 20.50 (tonf-m) is reached with respect to an axial load of 125.13 (tonf). On the other hand, the specimen without reinforcement reaches a moment of 18.20 (tonf-m) with respect to an axial load of 104.76 (tonf).

***Keywords*:** Carbon fibers polymers – resistance – increase -axial

1. Introduction

Currently, failing to comply with development principles and guidelines is a recurring theme worldwide, which immediately results in the development of designs with safe components with reduced limits, so it is normal for specific occasions, such as tremors or earthquakes, to cause extensive damage. , not exclusively to the aforementioned structures, but also to their inhabitants, and said damage goes through the handicap of the construction or even the collapse, as happened in 2021 with the Surfside multifamily operating in Miami, United States of America.

Another unfortunate case was the collapse of the Space apartment complex, which occurred on October 12, 2013, in Medellín, Colombia. The 23-story, four-basement building experienced a complete collapse, killing eleven people. Given this news, an investigation was immediately initiated by the Universidad de Los Andes de Colombia, who indisputably presumed that the aforementioned building imploded due to the lack of limit of the safe components, specifically a set of walls located on the main level of the collapsed building.

As should be visible in the referenced models, the absence of a sufficient boundary of the primary components, the concrete walls, can lead to undesirable circumstances, in any case causing the rupture of the affected structures.

In the Peruvian case, the circumstance could be much more serious, since according to the Peruvian Construction Office (CAPECO), at this moment 80% of the houses worked in Peru are the result of self-development, a wide practice in the country, that is part of the development of structures without depending on a regulated design or development plan that authorizes minimum standards.

2. Methodology

To carry out this research work, the following stages must be developed:

a. Identification and selection of materials

b. Evaluation of the structural situation of a single-family home.

c. Evaluation of the state of charges before the change of use, and after the change of use.

d. Design of mixtures and manufacture of cylindrical test tubes.

and. Testing of unconfined concrete specimens and concrete specimens wrapped with carbon fiber reinforced polymer (CFRP).

e. Analysis of the results obtained in the laboratory.

f. Structural interaction modeling using a 3D model in Cypecad software.

g. Comparison of the results of modeled analyzes and laboratory tests.

Materials

- Ready mixed concrete
- Carbon fiber reinforced polymer CFRP or Carbon Fiber
- Epoxy
- Water
- Test tube molds
- Abrahams cone

Tools

- sclerometer
- Cypecad Software
- Architectural and structural plans of the building
- Soil study reports of the area

Collection of information on the structural state of a column of f'c 210 kg/cm2.

Evaluation and collection of information on the current state of a column of f'c 210 kg/cm2

3. Results

To obtain results, a critical analysis of the values obtained through laboratory tests has been used, given that the vast majority of these only approximated the numerical models of deformations used or proposed in theory, which is why they were analyzed these variations.

The first result consists in characterizing the materials, such as carbon fibers and concrete specimens, to be able to use them in a finite element computational model, which can indicate the degree of improvement when applying these materials in the section of the wall, another approach It consists of selecting and determining the current resistance of the existing walls, however the improvement of the particular project would be mixed with the general improvement that this procedure can cause in any project, for this reason the improvement is proposed based on average values only.

3.1 Tensile strength tests on carbon fibers

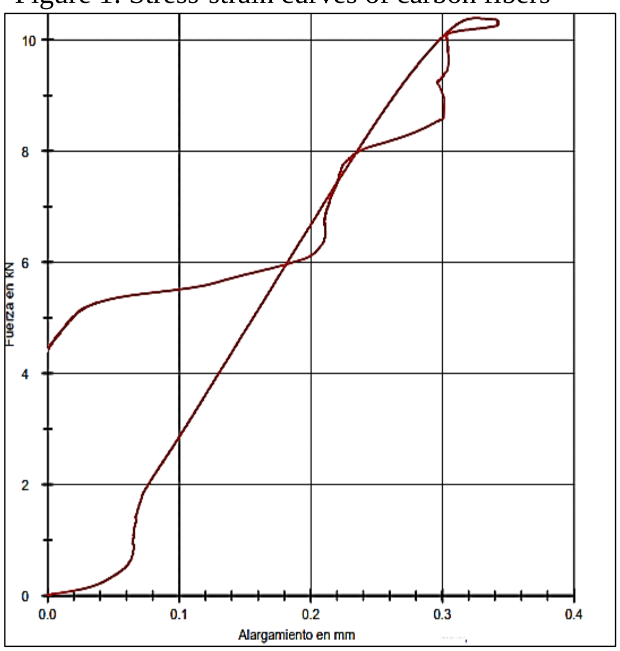
In order to evaluate the tensile strength of carbon fibers, a carbon fiber specimen has been tested, which was subjected to a uniaxial tensile strength test, with unit strain monitoring, given that it was susceptible to the problem of slippage of the specimen. The result obtained is shown below:

Table 1: Mechanical properties of carbon fiber.

Sample	Modulus of Elasticity (Gpa)	Maximum Load (kN)	Maximum Load (kg-f)	Observations
1	111	10.4	1061	The sample did not arrive fractured, due to its nature it slipped during the test

The results obtained show that the modulus of elasticity of the fiber was 111GPa, however, due to technical problems of support slippage, the failure load could not be determined, being a recurring problem in this type of tests, the slippage between the. The sample and the fasteners modify the final value, however, the elongation vs. deformation graph can be fully appreciated in the following graph, seeing that the reason why the force and displacement decreased is due to the slippage of the sample.

Figure 1: Stress-strain curves of carbon fibers



Note: Own source.

3.2 Stress-strain curve of unconfined concrete

To qualify the stress-strain curve of unconfined and confined concrete, the results obtained from the compression test of 06 confined concrete specimens and 03 unconfined concrete specimens have been used. The specimens used for the development of laboratory tests have a layer of carbon fiber, which can be seen in the image, this for the confined test tubes, for the unconfined test tubes, test tubes with free faces have been used. The laboratory tests were developed in the laboratory of the Pontificia Universidad Católica del Perú.

Figure 2: Specimens wrapped with carbon fiber and specimens without carbon fiber

Note: Own source.

3.3 Laboratory test results

It has been possible to identify the following properties of the specimens without confinement, in each case it can be seen that the resistance to compression is greater than the nominal resistance of 210 kg/cm2, obtaining:

Table 4: Mechanical properties in unconfined specimens.

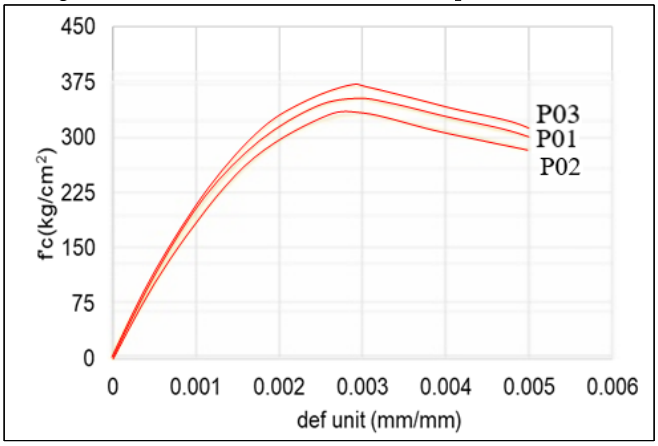
Specimen	Breaking force (kg)	Nominal resistance (kg/cm2)	Measured resistance (kg/cm2)
P01	283	210	368
P02	277	210	355
P03	301	210	387
P04	319	210	409
P05	287	210	368
P06	287	210	368

Note: Own source.

The results obtained from the compressive strength test of the 6 unconfined specimens show that the lowest compressive strength value was 355 kg/cm2, with a maximum value of up to 409 kg/cm2. It should be clarified that the nominal compressive strength of the concrete samples was 210 kg/cm2 at 28 days of curing, comparing with the average value 375.88 kg/cm2 at 28 days, there is a higher value by 21 % on average, this increase must be taken into account when carrying out the comparative analysis of the improvement.

In addition to the compressive strength values shown in the previous tables, the stress-deformation curves of the cylindrical specimens tested are shown below.

Figure 3: Stress strain curve of the specimens.



Note: Own source. P03

Figure 3 shows the stress-strain curve of the specimen P01, P02 and P03. As can be seen, in this stress-deformation diagram, for sample P01 the maximum compression was 368 kg/cm2, with a unit deformation of 0.003, according to the data obtained in the laboratory, for sample P02, the resistance to maximum compression was 355 kg/cm2, where a value of 0.003 unit strain was obtained parallel to the compression stresses, finally, for sample P03 it was found that the maximum compression resistance was 387 kg/cm2, value that a unitary deformation of 0.003 was reached, as shown in the figure, for the case of the unitary deformation, it has been possible to see a great similarity with the assumed values of deformation of the ACI, which recommend a value of 0.003 of strain at maximum compression.

The stress-strain curves associated with the specimens P04, P05 and P06 contain essentially the same shape and the same characteristics presented in the first four, which is why only the first 3 graphs are shown, seeing that each one of them is completely similar. and uniforms, in addition to being in accordance with the ACI standard.

3.4 Stress-strain curve of confined concrete

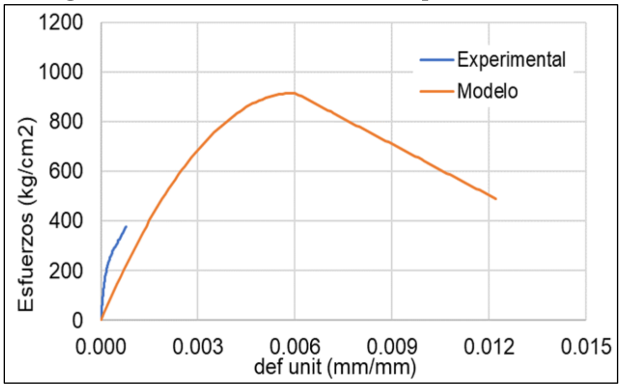
The results obtained from the compression resistance test of the concrete specimens reinforced with carbon fibers can be seen in table 5, where the mechanical properties obtained from the tests carried out are presented. As can be seen, from this table the resistance to compression fluctuates from 832 kg/cm2 to 1078 kg/cm2, with an average value of 942 kg/cm2, which translates into an increase in resistance of up to 150.66%. with respect to the average value of the initial samples, on the other hand there is an increase of 348.57% with respect to the nominal value, this also warns us that the concrete has a greater resistance than expected, causing the steel elements to reach a yield of a way other than calculated.

Table 5: Mechanical properties of concrete confined with carbon fiber.

Sample	Fiber	fc (kg/cm2)	E(kg/cm2)
M01	Si	916	465438
M02	Si	832	576057
M03	Si	1078	437992

Note: Own source.

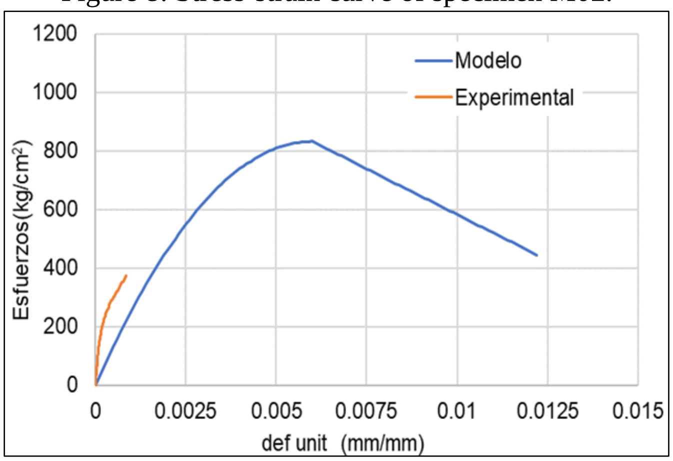
Figure 7: Stress-strain curve of specimen M01



Note: Own source.

Figure 7 shows the stress-strain curve of the M01 specimen, in which the maximum compressive strength of 916 kg/cm2 can be seen with a unit strain of 0.006, another aspect to highlight is that the experimental result can only go up to certain point, the complete curve could not be taken due to limitations in the press machine.

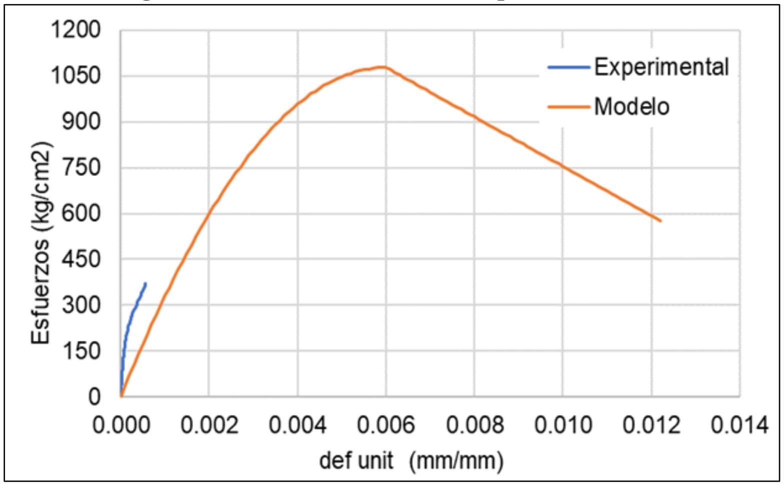
Figure 8: Stress-strain curve of specimen M02.



Note: Own source.

Figure 8 shows the stress-deformation curve of the M02 specimen, in which the maximum compressive strength of 832 kg/cm2 can be seen with a unitary deformation of 0.005, in the same way it has been possible to see only part of the stress-strain curve, since the tests are not capable of taking all the measurements of the complete curve.

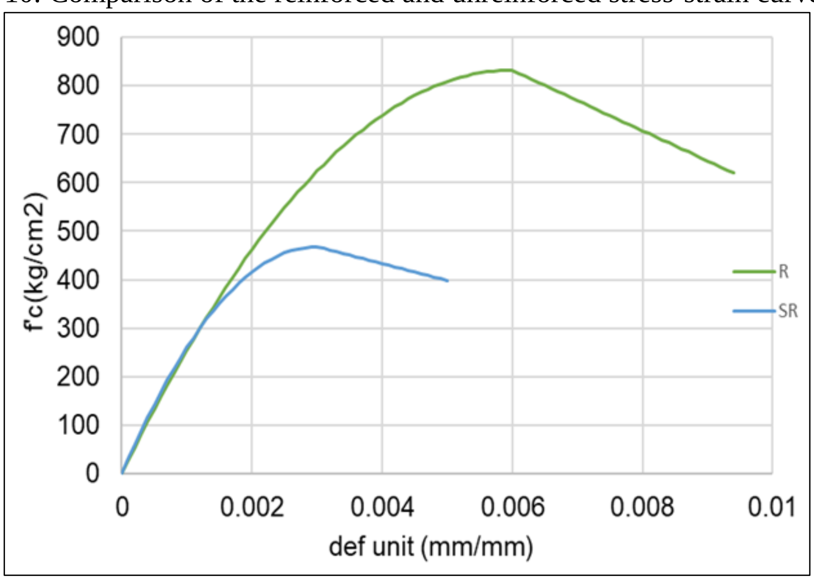
Figure 9: Stress-strain curve of specimen M03.



Note: Own source.

Figure 9 shows the stress-strain curve of the M02 specimen, in which it can be seen, the maximum compressive strength of 1078 kg/cm2, a unit strain of 0.006 units.

Figure 10: Comparison of the reinforced and unreinforced stress-strain curves.



Note: Own source.

By way of comparison, Figure 10 shows an overlay of the stress-strain diagrams of concrete confined with carbon fibers (R) and concrete without confinement (SR). From these graphs, the increase in resistance to uniaxial compression caused by the confinement of the carbon fibers can be clearly seen; Likewise, an increase in the deformation capacity provided by the confinement of the carbon fibers can be seen. To better understand some aspects related to these deformations, we can take the ductility of the specimen, comparing the increase in said ductility, for the In the case of the unconfined specimen, there is a value of 0.005/0.001=5, considering that the ductility is the product of the division of the ultimate deformation and the creep deformation, for the confined element there is a value of 0.09/0.004= 22.5, which is a substantial increase of more than 400% in ductility of the material, in the same way for over-strength an increase of 150% can be had, as explained in the previous sections, all this improves the material, but it also makes it more difficult to plasticize, which in columns or plates is an advantage, since it seeks to keep these elements intact, however, in beams care must be taken when estimating the damage to the elements, if they are more reinforced or with enough overstrength, the damage capacity of such elements can be lost, leaving the structure without a clear failure mechanism.

Subsequently, the modeling of reinforced concrete walls has been elaborated with the Cypecad and Etabs software, in order to obtain different types of results, respectively, the reasons for both modeling will be explained, finally the following values of the properties of the the materials:

Table 6: Carbon fiber tensile strength values.

Middle value	3100 Mpa
Minimum value	>2800 Mpa
5% fractal value	3000 Mpa
95% fractal value	3600 Mpa

Note: Sika Source (2023)

Table 7: Tensile stiffness values of carbon fiber.

Middle value	165000 Mpa
Minimum value	>160000 Mpa
5% Fractal Value	162000 Mpa
95% fractal value	180000 Mpa

Note: Sika Source (2023)

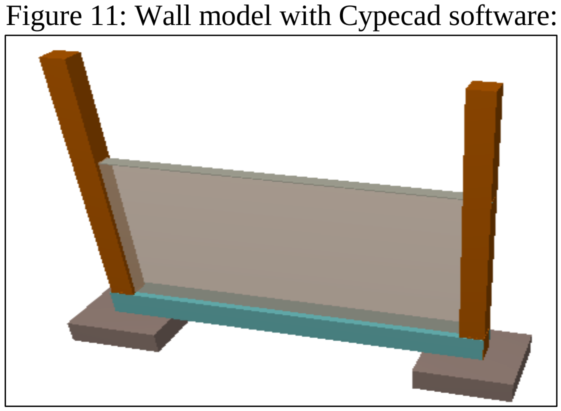
Each one of these values are the product of the values recommended by Sika, since average values are being used, for the modeling of the wall the concrete wall has been considered as such, plus the lateral confinements in each of the corners, as shown. you can see in the following figures:

Table 8: Mechanical properties of Wrap 600 carbon fibers.

Laminate Nominal Thickness	1.30 mm	
Laminate Nominal Cross Section	1300 mm² por (m.) de ancho	
Resistencia a tracción del Laminado	**Promedio** **f_{fu}= 1,075 MPa [10,960 kg/cm²]**	**De diseño[1]** **f_{*fu}= 950 MPa [9,690 kg/cm²]**
Módulo de Elasticidad a Tracción del Laminado	**Promedio** E_f= 58,460 MPa [596,000 kg/cm²]	**De diseño[1]** E^*_f= 53,100 MPa [541,400 kg/cm²]
Elongación a Rotura del Laminado	ε^*_{fu} =1.80 %	

Note: Sika Source (2023)

Figure 11: Wall model with Cypecad software:



Note: Cypecad Source.

4. Conclusion

The use of carbon fiber polymers in concrete walls improves the capacity of concrete, which has been identified in the graphs of laboratory tests using concrete test tubes, which in turn generate an increase in maximum resistance. average of a value of 375.88 kg/cm2, to an average value of 942 kg/cm2 in the resistance to axial compression, for the value of the maximum unitary deformation reached there has been an increase on average of 0.003 to 0.006, which corresponds to At 200% of the initial value, with respect to the increase in axial deformation, there has been an increase of 150.66% on average with respect to the result of compression resistance, with respect to the nominal resistance there has been an increase of 348.57%, which gives us an alert on the reinforcement of structures, using this reinforcement in vertical elements such as columns or plates, but leaving or correctly verifying its use in beams, given the search for plasticization in beams, causing excess resistance in the beams.

Acknowledgements

We thank the Peruvian University of Applied Sciences for promoting and sponsoring scientific research in favor of improvement in Peruvian engineering.

References

[1] INEI, (2007). Estadísticas sobre estudio de las viviendas en Lima. Instituto Nacional de Estadística.
[2] Choi1, Myung Kwan y Sorrasak, (2021). S Seismic Retroftting of RC Circular Columns Using Carbon Fiber, Glass Fiber, or Ductile PET Fiber. Engineering Structures. Volume 275. 2022.115100.ISSN 0141-0296. https://doi.org/10.1016/j.engstruct.2022.115100
[3] Huaco y Jirsa, (2017). Cyclic Behavior of CFRP as Diagonal Ties and Anchors to Rehabilitate Severe Damaged Masonry Wall. Engineering Structures. Volume 275. 2022.115100.ISSN 0141-0296. https://doi.org/10.1016/j.engstruct.2022.115100.
[4] Di Luccio, Michel y Ferrier (2017). Performance of mansory wall retrofitted using CFRP sheets and acnchors. Santiago de Chile: 16th World Conference on Earthquake Engineering, 16WCEE 2017.
[5] Ruqayyah I., et al (2019). Analytical modelling and design of partially CFRP-wrapped thin-walled circular NCFST stub columns under axial compression.
[6] Seiyed A. et al (2020). An Energy-Based Concept for Yielding of Multidirectional FRP Composite Structures Using a Mesoscale Lamina Damage Model. 10.3390/polym12010157
[7] Hadi, T.D. et al (2014). Conducta de las secciones de concreto construidas con centro hueco envueltas con CFRP con varias direcciones de fibra. Instituto Nacional de Tecnología de Karnata.
[8] Sathwik, M.C. et al (2019). Investigaciones de ensayo y matemáticas sobre la forma de comportamiento a la compresión de ejemplos sustanciales en forma de barril envueltos en CFRP expuestos a diversas condiciones de carga.
[9] Kerlinger (2002). Metodología de la investigación.
[10] Hernández-Sampieri, R., Fernández Collado, C. y Baptista, L. P. (2010). Metodología de la investigación.
[11] Borja S., M. 2012. Metodología de la Investigación Científica para ingenieros.
[12] Phidias, A. (2012). Los proyectos de investigación.