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# Compressive Strength and Ductility of Concrete Wrapped by CFRP

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**Abstract**

Existing reinforced concrete (RC) columns may be structurally deficient due to variety of reasons such as improper transverse reinforcement, flaws in structural design, insufficient load carrying capacity, etc. Fiber reinforced polymer (FRP) is a new generation of materials which illustrates in order to enhance concrete compressive strength and ductility. Among the FRP types, Carbon fiber reinforced polymer (CFRP) is more common. CFRP can be effectively used for strengthening and confinement the deficient RC columns. This research conducts to evaluate the behavior of this fiber in improvement of aforementioned quantities. In this investigation, three categories of compressive strength of concrete were selected. The samples were warped with 0, 1, 3, and 5 layers of CFRP were subjected under stress-strain tests. The results display that carbon fiber is more effective in enhancing the compressive strength and ductility. Fiber performance is more effective on low-strength concretes, and its effective role decreases with increasing the number of layers.

***Keywords:*** CFRP; FRP Composite Wrapping; Compressive strength; Ductility

## 1.Introduction

Currently, repairing and retrofitting of defective structures is considered as one of the important issues of civil engineering all over the world. Fiber Reinforced Polymer (FRP) systems can be used with the aim of rebuilding or maintaining strength of a worn out structural member, repairing or retrofitting of undamaged structural members in order to endure the increased load due to changing of the structure operation or compensating for design and implementation mistakes.

### 1.1.Background

In Europe, FRP systems were developed as alternates to steel plate bonding. Bonding steel plates to the tension zones of concrete members with adhesive resins were shown to be viable techniques for increasing their flexural strengths. This technique has been used to strengthen many bridges and high rise buildings around the world. Because steel plates can corrode, leading to a deterioration of the bond between the steel and concrete, and because they are difficult to install, requiring the use of heavy equipment, researchers have looked to FRP materials as an alternative to steel. Experimental work using FRP materials for retrofitting concrete structures was reported as early as 1978 in Germany. Previous research and field applications for FRP rehabilitation and strengthening are described in ACI 440.2R-17 (2017). In Europe, the International Federation for Structural Concrete (FIB. 2001) published a bulletin for design guidelines, entitled "externally bonded FRP reinforcement for reinforced concrete structures"[1-17].

### 1.2. The Performance of Confinement

Confinement is generally applied to members in compression, with the aim of enhancing their load carrying capacity or, in cases of seismic upgrading, to increase their ductility. Traditional confinement techniques rely on either steel hoops or steel jackets for upgrading. Indeed, it is well known that increasing the confinement action enhances the concrete strength and ductility and, in addition, prevents slippage and buckling of the longitudinal reinforcement. In seismic problems, existing upgrading (either strengthening or retrofitting) techniques are typically based on increasing the confinement pressure in either the potential plastic hinge region or over the entire member. This technique can also be useful in lap-splices zones.

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Several experimental studies on concrete confined with FRP have been carried out which confirm the viability of this solution. Current analytical and numerical research aims at defining appropriate constitutive laws for FRP-confined models. In the field of design of FRP jackets extensive experimental work has been conducted by Seible et al (1995), and numerical and analytical work by Monti et al (2001), with the task of identifying suitable design equations that optimize the FRP jacket thickness as a function of the desired upgrading level [18-29].
Minafò et al. (2019) [30] presented a model to assess the confinement pressure for concrete elements bonded with CFRP. They confirmed this model by finite-element analyses and experimental procedures. In the other research, Haj Seiyed Taghia et al. (2020) [31] applied a statistical method to investigate economically the influence of CFRP layers and the dosage of cement content on concert performance. Moreover, Haj Seiyed Taghia et al. (2020) [32] compared the performance of carbon and glass fibers on concrete behavior. The results illustrated that the influence of both types of fibers is greater on enhancement of compressive strength and failure strain for higher strength concrete. On the contrary, fibers were more effect on lower strength concrete with reference to energy absorption and ductility.
In this research, the effect of CFRP on compressive strength and ductility are investigated.

## 2.Experimental Program

In this section, the material properties, preparation and curing are described separately.

### 2.1. Material Properties

The ordinary Portland type-II cement is used in the entire specimens. The specimens were made according to ASTM C150 [33] and the gravel and sand aggregates are of river type in accordance with ASTM C33 [34].The sand sizes ranged from 0 to 4.75 mm with apparent weight in Saturated Surface Dry (SSD) state of 2650 kg/m$^3$, and its 24-hour water absorption is 1.5% and also the super plasticizers are of type P10-3R based on ASTM C494 [35]. CFRP is of type YC-N160 based on the properties presented in Table 1 and the consumed resin is of type epoxy DUR 300, in accordance with Table 2.

Table 1
Technical properties of CFRP

| Name | YC-N160 |
|---|---|
| **Fiber type** | High Strength Carbon Fibers |
| **Fiber tensile strength (**Mpa) | 4900 |
| **Tensile elasticity modulus (**Gpa) | 230 |
| **Areal Weight (**g/m$^2$) | 160 |
| **Fabric Thickness (**mm) | 0.09 |
| **Style** | Woven UD |

Table 2
Technical properties of Resin

| Property | Specification |
|---|---|
| **Mixing ratio** | A: B = 100:34.5 by weight. |
| **Tensile strength** | Curing 7 days, +23°C: 45 N/mm$^2$ |
| **Flexural modulus** | Curing 7 days , +23°C: 3000 N/mm$^2$ |
| **Tensile modulus** | Curing 7 days, +23°C: 3500 N/mm$^2$ |

### 2.2.Sample Preparation

In this research, a number of 12 samples were considered for 3 classes of compressive strength of concrete (20, 35, and 50 MPa). The concrete was constructed in the beginning and it followed by inserting it into the pre-prepared molds and then samples were set to harden at constant temperature and humidity for 24 hours. Mold shape was used, a cylindrical with dimensions of 15×30 cm. After 24 hours, the specimens are removed from the molds and are placed into a water pond with temperature of $20 \pm 2$°C for curing. The curing time of the samples was equal to 28 days in order to perform compressive strength and stress-strain tests. After 28 days, the samples were taken out from the pond and placed in the laboratory for drying the surface of the samples. Two days later, the samples were prepared in four modes with 0 (control sample), 1, 3, and 5 layers of CFRP warps and after 7 days, they were subjected to stress-strain tests (see Figure 1). The compression testing machine was used for testing the compressive strength of concrete. The load shall be applied slowly without shock and increased continuously until the resistance of specimen.
In this research, Cs and followed by the number stand for value of classes of compressive strength and Ls followed by the number stand for no. of CFRP layers.

Fig. 1. Samples preparation for stress-strain tests

## 3. Results and Discussion

This section deals with the investigation of the influence of using CFRP with different layers on the compressive strength and ductility of concrete samples.

### 3.1. The Stress-strain Tests

The stress-strain tests were performed on the 15 cm ×30 cm cylindrical samples at the age of 28 days and shown in Figures 2 through 4 for three classes of concrete (i.e. C20, C35 and C50) and different layers of CFRP sheets. The tests performed in compliance with ASTM C469 [36].

Since the concrete loses its integrity in a strain greater than 1% and the rebar reaches its ultimate endurable strain and also the cohesion between the concrete and the rebar decreases intensively, thus, the ultimate strain value is limited to 1% in all diagrams 2 to 4 [34].

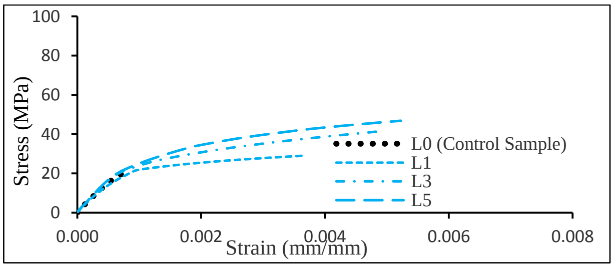


Fig. 2. Stress-strain diagrams for C20 classes

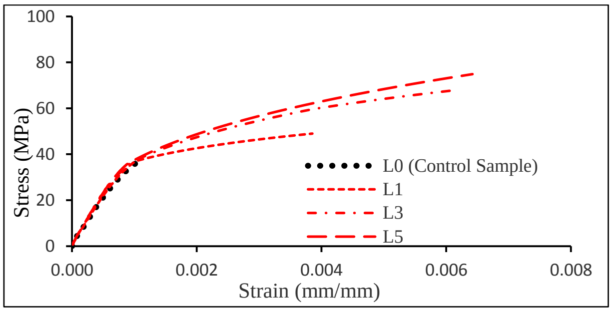


Fig. 3. Stress-strain diagrams for C35 classes

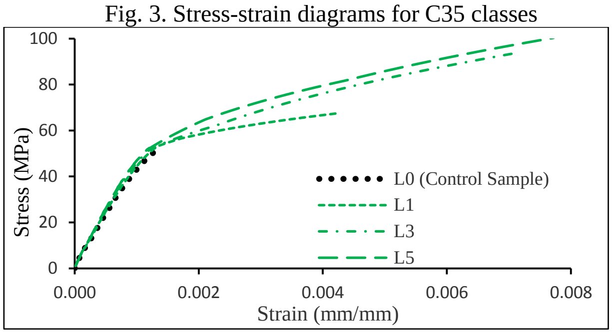


Fig. 4. Stress-strain diagrams for C50 classes

Compressive strength and ductility of concrete samples have been extracted from Figures 2-4.

#### 3.1.1. Compressive Strength

The maximum values of stress in Figures 2 through 4 have been obtained and considered as compressive strength for different classes of concrete. The effect of CFRP layers on the compressive strength of the samples is shown in Figure 5.

As it can be seen in Figure 5, the compressive strength of the concrete samples increased with the increase of the number of CFRP sheets due to the effect of bonding and confinement.

The percentage of increase in compressive strength in the samples wrapped by carbon fiber is shown in Figure 6. The effect of this fiber on increasing in compressive strength decreases with increasing concrete strength from 20 MPa to 50Mpa. Moreover, this diagram indicates that the effect of fibers on the rate of compressive strength growth would be less with increasing the number of warped fibers. It can attributed to the significant role of concrete integrity for more FRP layers.

#### 3.1.2. Ductility

The ductility of the cylindrical 15 cm × 30 cm samples is defined by dividing the failure strain over the yielding strain, this is in accordance to ASCE41-

13 [37].The yield strain was estimated by the following procedure: Using MATLAB software (2017b) [38] to make the stress-strain curve of the sample an equivalent bilinear then the intersection of the lines is referred as the yield strain.

Figure 7 indicates that concrete enclosed with carbon fiber is almost more ductile for less-strength concrete.

The percentage of ductility growth in concrete warped with carbon fibers is shown in Figure 8. The role of fibers decreases in ductility improvement by increasing the number of CFRP rounds. Again, it can attributed to the significant role of concrete integrity for more FRP layers.

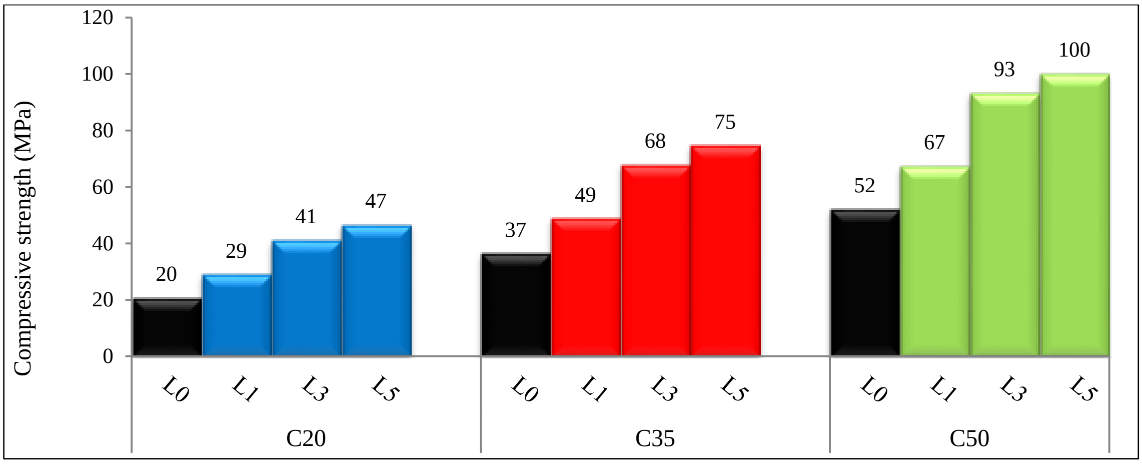


Fig. 5. Compressive strength of cylindrical samples

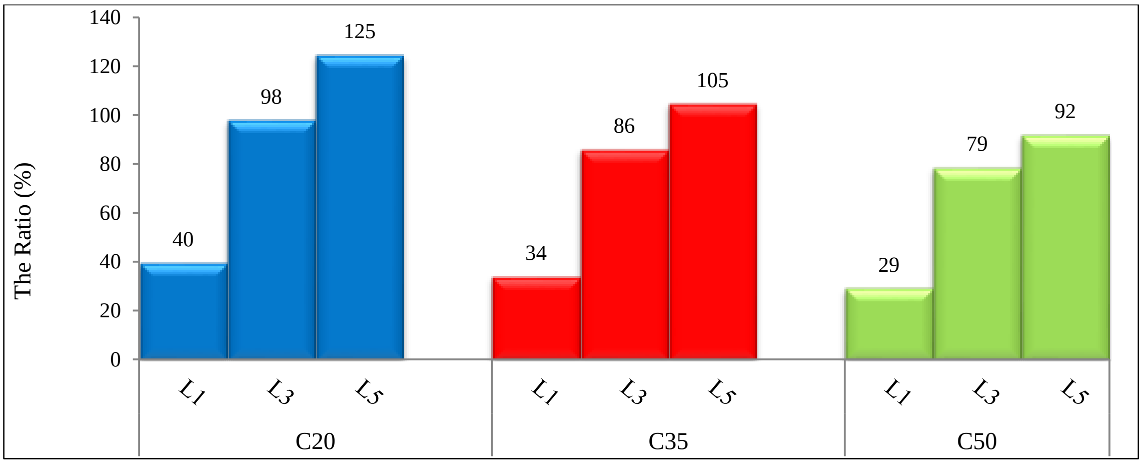


Fig. 6. The ratio of the increase in the compressive strength of samples with increasing number of CFRP layers relative to samples without CFRP

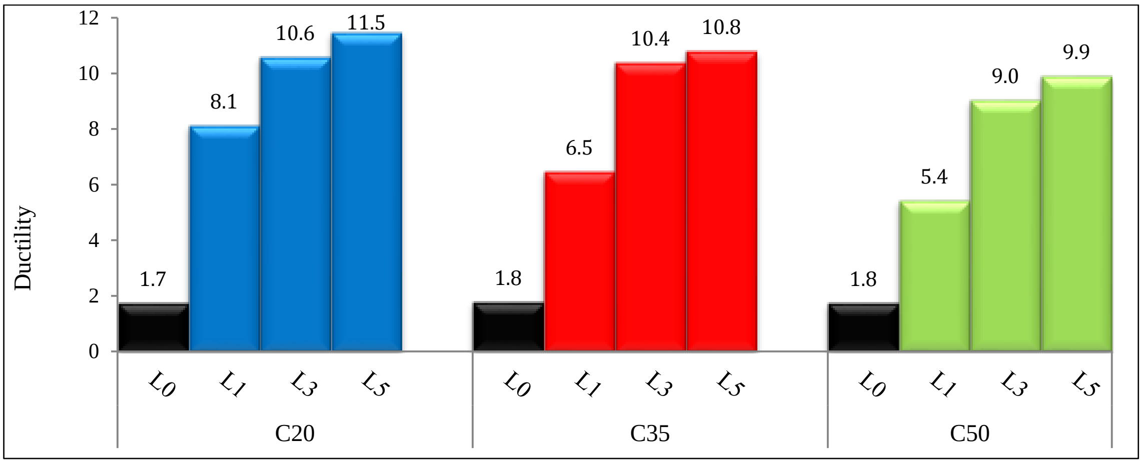


Fig. 7. Ductility of cylindrical samples

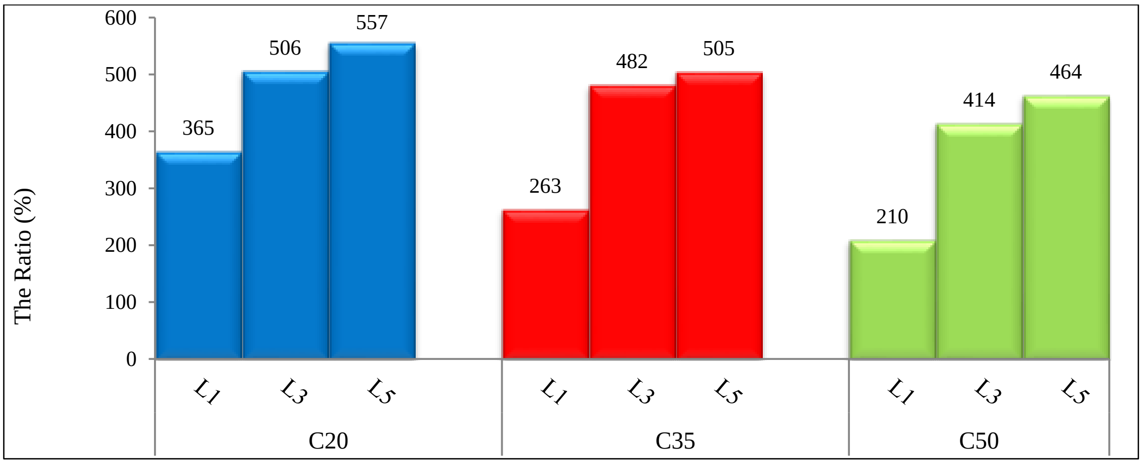


Fig. 8. The ratio of the Ductility of CFRP strengthened samples regarding to non-strengthened samples (%)

## 4. Conclusion

According to experimental works, the result of this research is finalized as followings:

1- The results showed that the fibers are effective in improving concrete compressive strength and ductility specially applying on low-strength concretes.
2- By increasing the number of CFRP rounds, the effective role of this fiber decreases in improving concrete compressive strength and ductility.

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## References

[1] Fleming, C. J., and King, G. E. M., “The Development of Structural Adhesives for Three Original Uses in South Africa., RILEM International Symposium, Synthetic Resins in Building Construction, Paris; 1967: 75-92.

[2] Wolf, R., and Miessler, H. J., “HLV-Spannglieder in der Praxis. Erfahrungen Mit Glasfaserverbundstaben”, Beton, 1989 (2): 47-51.

[3] Meier, U., “Bridge Repair with High Performance Composite Materials”, Material und Technik; 1987 (4): 125-128.

[4] Rostasy, F. S. (1987). Bonding of Steel and GFRP Plates in the Area of Coupling Joints. Talbrucke Kattenbusch, Research Report No. 3126/1429, Federal Institute for Materials Testing, Braunschweig, Germany.

[5] Fardis, M. N., and Khalili, H., “Concrete Encased in Fiberglass Reinforced Plastic”, ACI JOURNAL, Proceedings; 1981, 78 (6): 440-446.

[6] Katsumata, H., Kobatake, Y., and Takeda, T., “A Study on the Strengthening with Carbon Fiber for Earthquake- Resistant Capacity of Existing Concrete Columns. Proceedings from the Workshop on Repair and Retrofit of Existing Structures, U.S.-Japan Panel on Wind and Seismic Effects, U.S.-Japan Cooperative Program in Natural Resources, Tsukuba, Japan; 1987: 1816-1823.

[7] Nanni, A., “Concrete Repair with Externally Bonded FRP Reinforcement”, Concrete International; 1995, 17 (6): 22-26.

[8] Neale, K. W., “FRPs for Structural Rehabilitation: A Survey of Recent Progress,” Progress in Structural Engineering and Materials; 2000, 2(2): 133-138.

[9] Dolan, C. W., Rizkalla, S. H., and Nanni, A., “Fourth International Symposium on Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures”, SP-188, American Concrete Institute, Farmington Hills, MI; 1999.

[10] Sheheta, E., Morphy, R., and Rizkalla, S., “Fourth International Symposium on Fiber Reinforced Polymer Reinforcement for Concrete Structures”, 1999, SP-188, C. W.

[11] Saadatmanesh, H., and Ehsani, M. R., (1998). Second International Conference on Composites in Infrastructure”, ICCI; V. 1 and 2, Tucson, AZ, 1998, 1506 pp.

[12] Benmokrane, B., and Rahman, H., “Durability of Fiber Reinforced Polymer (FRP) Composites for Construction”, University of Sherbrooke, Canada; 1998.

[13] Neale, K. W., and Labossière, P., “State-of-the-Art Report on Retrofitting and Strengthening by Continuous Fibre in Canada. Non-Metallic (FRP) Reinforcement for Concrete Structures”, V. 1, Japan Concrete Institute, Tokyo,Japan; 1997: 25-39.

[14] Hassan, T., and Rizkalla, S., “Flexural Strengthening of Prestressed Bridge Slabs with FRP Systems”, PCI Journal; 2002, 47 (1): 76-93.

[15] Shield, C. K., Busel, J. P., Walkup S. L., and Gremel, D. D., “Proceedings of the Seventh International Symposium on Fiber Reinforced Polymer for Reinforced Concrete Structures (FRPRCS-7)”, SP-230, American Concrete Institute, Farmington Hills, MI; 2005, 1708 pp.

[16] ACI 440.2R-17. Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures; 2017.

[17] FIB. Externally Bonded FRP Reinforcement for RC Structures. FIB, Lausanne, 2001, 138 pp.

[18] Chai, Y. H., Priestley, M. J. N. and Seible, F., “Seismic retrofit of circular bridge columns for enhanced flexural performance”, ACI Structural Journal; 1991, 88(5): 572-584.

[19] Saadatmanesh, H., Ehsani, M. R. and Li, M. W., “Strength and ductility of concrete columns externally reinforced with fiber composite straps”, ACI Structural Journal; 1994, 91(4): 434-447.

[20] Nanni, A. and Bradford, N. M., “FRP jacketed concrete under uniaxial compression”, Construction and Building Materials; 1995, 9(2): 115-124.

[21] Seible, F., Priestley, M. J. N. and Innamorato, D., “Earthquake retrofit of bridge columns with continuous fiber jackets. In Design guidelines”, Advanced composite technology transfer consortium, 2, Report No. ACTT-95/08, University of California, San Diego, USA; 1995.

[22] Picher, F., Rochette, P. and Labossière, P., “Confinement of concrete cylinders with CFRP”, In Proceedings of 1st International Conference on Composite Infrastructures, Tucson, Arizona, USA; 1996: 829-841.

[23] Matthys, S., Taerwe, L. and Audenaert, K., “Tests on axially loaded concrete columns confined by FRP sheet wrapping”, In Proceedings of the 4th International Symposium on FRP for Reinforced Concrete Structures, Baltimore, USA; 1999: 217-228.

[24] Mirmiran, A. and Shahawy, M., “Behavior of concrete columns confined by fiber composites”, Journal of Structural Engineering, ASCE; 1997, 123(5): 583-590.

[25] Saadatmanesh, H., Ehsani, M. R., and Jin, L., “Seismic strengthening of circular bridge piers with fiber composites”, ACI Structural Journal; 1997, 93(6): 639-647.

[26] Spoelstra, M. R. and Monti, G., “FRP-confined concrete model”, Journal of Composites for Construction, ASCE; 1999, 3(3): 143-150.

[27] Seible, F., Priestley, M. J. N. and Innamorato, D., “Earthquake retrofit of bridge columns with continuous fiber jackets. In Design guidelines”, Advanced composite technology transfer consortium, 2, Report No. ACTT-95/08, University of California, San Diego, USA; 1995a.

[28] Monti, G., Nisticò, N. and Santini, S., “Design of FRP jackets for upgrade of circular bridge piers”, Journal of Composites for Construction, ASCE, in print; 2001.

[29] Triantafillou, T. C., “Seismic retrofitting of structures using FRPs”, Progress in Structural Engineering and Materials; 2001, 3(1), in print.

[30] Minafò, G., Rezaee-Hajidehi, M., & Giambanco, G., “A Mechanical Approach for Evaluating the Distribution of Confinement Pressure in FRP-Wrapped Rectangular Columns”, Journal of Engineering Mechanics, ASCE; 2019, 145(12). DOI: 10.1061/(ASCE)EM.1943-7889.0001673.

[31] Haj Seiyed Taghia, S. A., Darvishvand, H. R., Ebrahimi, M., “Economic Analyses for Low-Strength Concrete Wrapped with CFRP to Improve the Mechanical Properties and Seismic Parameters”,

J. Constr. Eng. Manage.; 2020, 146(3): 04019117. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001760.
[32] Haj Seiyed Taghia, S.A., Darvishvand, H.R., Asadi, S. et al., "A comparative study on the implementation of carbon and glass fibers wrappings to improve the compressive strength and seismic behavior of concrete", Asian J Civ Eng 21, 2020: 1389–1398. https://doi.org/10.1007/s42107-020-00285-5.
[33] ASTM C150-07. Standard specification for portland cement. American Society For Testing And Materials; 2007.
[34] ASTM C33-03. Standard Specification for Concrete Aggregates; 2003.
[35] ASTM C494-05. Standard specification for chemical admixtures for concrete. American Society For Testing And Materials; 2005
[36] ASTM C469. The Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression; 2014.
[37] ASCE 41-13. Seismic evaluation and retrofit of existing buildings; 2013.
[38] Matlab Computer programming language v-2017.