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Behaviour of Concrete Confinement by PVC Tubes and Strengthened with Carbon Textile-Reinforced Concrete

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ABSTRACT

This paper investigates the effect of concrete confinement using a polyvinyl chloride (PVC) tube and the strengthening of this confinement with single, two, and three layers of carbon textile-reinforced concrete (CTRC). Forty-five samples were studied and divided into three diameter groups (100, 150, and 200 mm). Each group was further divided into three subgroups based on length. The study examined unconfined concrete, PVC-tube-confined concrete, and CTRC-strengthened concrete. The results indicate an increase in the peak load capacity of the PVC-confined samples from 29% to 64.2% compared to the unconfined samples for each subgroup, while the increase in the peak load capacity of the CTRC-strengthened samples was from 79% to 131.2% compared to the unconfined samples for each subgroup. The peak load of the CTRC-strengthened samples increased from 9.2% to 65.56% compared to the confined samples for each subgroup. These findings demonstrated that the PVC tube confinement and CTRC strengthening enhance the resistance of the samples to the axial compressive strength of the concrete. This effect depends on the thickness of the PVC tube and the diameter of the samples, with pipe thickness having a significant impact and diameter having a particularly pronounced effect, especially when the length-to-diameter ratio is less than or equal to 2.

1. INTRODUCTION

To improve the properties of concrete, it is common to combine it with various materials to enhance its characteristics and durability. Traditionally, steel tubes have been used to reinforce concrete due to their strength and rigidity. When steel tubes are used and filled with concrete, these two elements combine the compressive strength of concrete with the tensile strength of steel, offering a wide range of applications in buildings, including long-span bridges and high-rise buildings [1, 2]. On the other hand, steel tubes incur high construction and maintenance costs and are susceptible to corrosion under harsh environmental conditions [3, 4]. Therefore, alternatives to steel tubes, including fiber-reinforced polymer (FRP) tubes, were used. While FRP tube is highly corrosion-resistant, its construction costs and brittleness limit its suitability for certain construction applications [5-9]. Conversely, polyvinyl chloride (PVC) tube is a superior alternative to steel and FRP tube because of its unique properties: a blend of polymer resins, stabilizers, and pigments, along with the ability to customize it to meet specific requirements [10, 11]. PVC is a universal option that outperforms other alternatives economically and is suitable for various infrastructure projects at different scales [12]. Polymer materials are widely used due to their exceptional properties, and these materials include tubes used for water supply and drainage, as well as materials used in the construction of cables and wires [13-15]. The construction sector has extensively exploited the properties of polymers in construction processes [16-26]. In many civil engineering applications, concrete-filled tubular columns are used because of their excellent seismic performance, characterized by high resistance to axial compression and stiffness [27]. These tubes delay the lateral expansion of the concrete and provide support to the tube to resist buckling by surrounding its outer core [28]. Confining the concrete within the tube places it under triaxial stress, thereby improving the pipe's compressive strength [29, 30]. From a sustainability perspective, using tubes eliminates the need for formwork, as the tubes used are recycled, reducing construction costs and time [31].

Therefore, the demand for and use of these types of columns has increased due to their ease of construction [32]. Concrete-filled plastic tubes are a promising option in the field, offering an excellent alternative to steel columns for their superior

durability [33]. PVC tubes have many features that qualify them for use as concrete columns, including their light weight, minimal need for maintenance, ease of manufacturing from recycled materials, which provides economical construction, excellent corrosion resistance, and, similarly, their resistance to chemicals, to which they have very high resistance [34]. Recent studies have addressed the use of PVC tubes to reinforce concrete, including [35]: Askari et al. investigated the behavior of unconfined and confined columns using unplasticized polyvinyl chloride (uPVC) tube reinforced with polypropylene fibers. Several parameters, including sample sizes, compressive strength, pipe type, and polypropylene fiber content in the concrete mix [36]. Woldemariam et al. evaluated confinement of concrete using a uPVC tube by studying several variables, including pipe wall thickness, concrete compressive strength, and length-to-diameter ratio (L/D) [37]. Hammadi et al. examined the effectiveness of full and partial confinement using PVC tube with varying pipe diameters, and the effect of changing the height-to-diameter ratio was investigated [38]. Chena et al. studied the strengthening of previously damaged columns with carbon fiber. The study focused on two factors: the degree of damage to the columns and the type of material used for strengthening, including engineered cementitious composite (ECC) in addition to polymer fabric, strengthening using carbon fibers embedded in textile-reinforced ECC (TRE), and strengthening using carbon fibers embedded in cement mortar textile-reinforced mortar (TRM) as a comparative sample [39]. Ling and Chin [39] examined the effect of concrete type on tube behavior by using plain concrete and glass-fiber-reinforced concrete (GFRC). It also investigated the effect of varying sample diameters (from 75 mm to 150 mm) and fiber content (from 0 to 0.15% of cement weight). Regarding confinement, the study considered both the use of PVC tubes and the absence of PVC tubes for the same parameters.

From this perspective, a deficiency was observed in some variables and types of strengthening that can be applied to PVC concrete-filled tubes. This study aims to bridge this gap by using a new strengthening method: Carbon textile-reinforced concrete (CTRC). It also investigates the effects of confinement and non-confinement, as well as the impact of variations in diameter, height, thickness of the PVC tube, and the number of CTRC layers for each case. CTRC technology relies on an inorganic cementitious binder (which offers fire resistance and durability compared to polymeric materials), unlike conventional carbon fiber-reinforced polymer (CFRP) technology, which utilizes organic polymer resins.

2. RESEARCH METHODOLOGY

This section will briefly present the experimental program of the study, construction materials used in preparing concrete samples, culminating in the required tests for PVC tube concrete.

2.1 The program of the experimental work

Forty-five cylindrical specimens (each specimen is an average of three tests) were created and divided into three groups according to diameter (100 mm, 150 mm, and 200 mm). Each group (each diameter separately) was further divided into three subgroups based on length (100 mm, 200 mm, and 300 mm). Each subgroup contains one specimen inside a PVC tube and three specimens surrounded by a PVC tube and strengthened with CTRC. There is also a reference specimen without PVC and CTRC for all specimens for comparison. Thus, the total number of specimens is 5 per subgroup, which investigates the effect of diameter and length on the behavior of the cylinders, which are considered variables in this study, in addition to thickness, as shown in Table 1. After preparing the molds, the PVC tubes were made to the required diameter and length. The fresh concrete was then placed inside a PVC tube for casting. A vibrating table was used for a few minutes to prevent clumping and expel air from the voids, as illustrated in Figure 1. Twenty-four hours after the casting process, all specimens were immersed in water for 28 days to harden. After hardening, the specimens were removed from the water and left to dry. The molds were then coated with CTRC, which was wrapped around PVC tubes using epoxy at a ratio of 1:4, as shown in Figure 2. They were left for 24 hours in the laboratory to be ready for testing using a compression testing device, as shown in Figure 3.

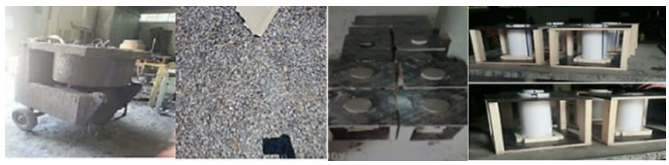


Figure 1. Model preparation stages

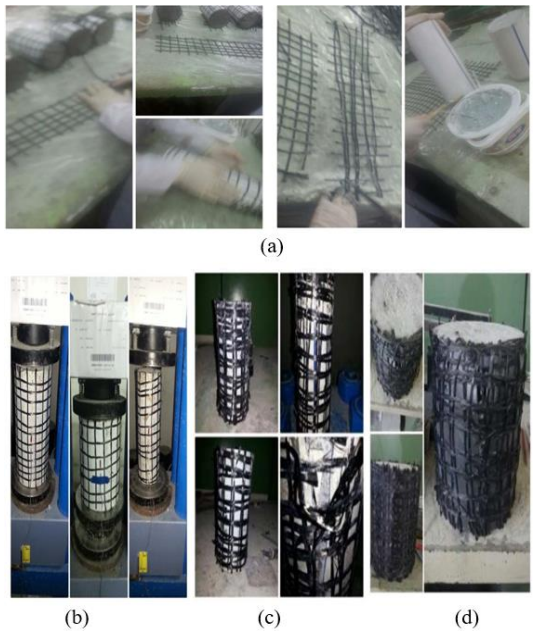


Figure 2. Preparation of a specimen with carbon textile-reinforced concrete (CTRC): (a) CTRC with epoxy, (b) specimen with one layer, (c) specimen with two layers, and (d) specimen with three layers



Figure 3. The curing and testing of the specimens

2.2 Raw materials properties

2.2.1 Cement

The cement is used as the primary binder for all concrete mixtures, ordinary Portland cement (OPC) Type 1. The physical and chemical requirements conform to the Iraqi Standard No. 5. 1984 [40].

2.2.2 Fine aggregate

In this investigation, local Iraqi sand was taken from the Al-Sidr Suburb in the Diyala Governorate with properties governed by the Iraqi Specification No. 45, 1984 [41]. Utilized as a fine aggregate after sieving and washing with clean water to remove all organic impurities, silt, and clay to ensure the production of high-quality concrete.

Table 1. Characteristics of cylinder concrete

Diameter (D) (mm)	Length (L) (mm)	Thickness (t) (mm)	L/D	ID Specimen	Type of Confinement
				D1L1-1	Without
				D1L1-2	Confinement With PVC
	100	2.5	1	D1L1-3	PVC + 1Layer CTRC
				D1L1-4	PVC + 2Layer CTRC
				D1L1-5	PVC + 3Layer CTRC
				D1L2-1	Without
		2.5		D1L2-2	Confinement With PVC
100	200		2	D1L2-3	PVC + 1Layer CTRC
				D1L2-4	PVC + 2Layer CTRC
				D1L2-5	PVC + 3Layer CTRC
				D1L3-1	Without
				D1L3-2	confinement with PVC
	300	2.5	3	D1L3-3	PVC + 1Layer CTRC
				D1L3-4	PVC + 2Layer CTRC
				D1L3-5	PVC + 3Layer CTRC
				D2L1-1	Without
				D2L1-2	Confinement With PVC
	100	3	0.67	D2L1-3	PVC + 1Layer CTRC
				D2L1-4	PVC + 2Layer CTRC
				D2L1-5	PVC + 3Layer CTRC
				D2L2-1	Without
				D2L2-2	Confinement With PVC
150	200	3	1.33	D2L2-3	PVC + 1Layer CTRC
				D2L2-4	PVC + 2Layer CTRC
				D2L2-5	PVC + 3Layer CTRC
				D2L3-1	Without
		3	2	D2L3-2	Confinement With PVC
	300			D2L3-3	PVC + 1Layer CTRC
				D2L3-4	PVC + 2Layer CTRC
				D2L3-5	PVC + 3Layer CTRC
				D3-L1-1	Without
				D3L1-2	Confinement With PVC
	100		0.5	D3L1-3	PVC + 1Layer CTRC
		4		D3L1-4	PVC + 2Layer CTRC
				D3L1-5	PVC + 3Layer CTRC
				D3L2-1	Without
				D3L2-2	Confinement With PVC
200	200	4	1	D3L2-3	PVC + 1Layer CTRC
				D3L2-4	PVC + 2Layer CTRC
				D3L2-5	PVC + 3Layer CTRC
				D3L3-1	Without
				D3L3-2	Confinement With PVC
	300	4	1.5	D3L3-3	PVC + 1Layer CTRC
				D3L3-4	PVC + 2Layer CTRC
				D3L3-5	PVC + 3Layer CTRC

Note: The letter D indicates the diameter, while the numbers one, two, and three indicate the diameters used (100, 200, and 150 mm), and the letters L refer to the lengths used (100, 200, and 300 mm). The numbers one through five, preceded by a descriptor, indicate the sample number within the same diameter and height range. Polyvinyl chloride (PVC), carbon textile-reinforced concrete (CTRC), length-to-diameter ratio (L/D).

2.2.3 Coarse aggregate

10 mm maximum size aggregate was used as a coarse aggregate for the concrete mixtures. It was obtained from the Al-Sider Suburb, an Iraqi city, with the characteristics according to the second version of the Iraqi Specifications No. 45, 1984 [41].

2.2.4 Mixing water

The conventional tap water was employed throughout the experimental program for the mixing and the subsequent curing processes.

2.2.5 Polyvinyl chloride tubes

This study used PVC tubes, which are among the most common types in Iraq. They were used in various diameters and lengths, divided into three groups as shown in Table 1, where Table 2 shows the properties of PVC tubes.

Table 2. The detailed properties of polyvinyl chloride (PVC) tubes

Color	Number of Specimens
Specific gravity	White
Density (kg/m^3)	1400 ± 20
Ultimate tensile stress (MPa)	49.5
Modulus of elasticity (MPa)	2265

2.2.6 Carbon textile-reinforced concrete

In this study, the fabric used to strengthen the tube was a carbon fiber textile mesh made of polyacrylonitrile with an aperture size of 2 × 2.5 cm. Table 3 shows the properties of this textile, and Table 4 shows the specifications of epoxy, where a polymer resin (epoxy) is utilized to impregnate these fibers to confine the PVC tube's concrete samples.

Table 3. The detailed properties of carbon textile-reinforced concrete (CTRC)

Material	12k CTRC
Weight (g/m^2)	160 ± 10
Thickness (mm)	0.2
Mesh size (cm)	2 × 2.5
Tensile strength (MPa)	3530
Tensile Modulus (GPa)	230
Color	Black

Table 4. Specifications of epoxy resin used in the study

Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Percent Elongation (%)	Density (g/cm^3)	Water Absorption (%)	Shear Strength (MPa)	Flexural Strength (MPa)
37	1800	7	1.1	1.5	29.6	63

2.3 Concrete mixture

Traditional concrete mixes were used in this study, with compressive strengths ranging from approximately 25 MPa at 7 days to 39 MPa at 28 days. All mix components and their quantities per cubic meter are shown in Table 5. Additionally, the mechanical properties of the hardened concrete are listed in Table 6.

Table 5. Mix proportions of concrete

Constituent	Weight per Cubic Meter of Concrete
Cement	450
Sand	750
Gravel	780
Water	202.5
w/c	0.45

Note: Water-to-cement ratio (w/c).

Table 6. Properties of concrete

Property	Normal Concrete Mix	
Compressive strength (MPa)	7 days 25	28 days 39
Splitting strength (MPa)	2.65	
Flexural strength (MPa)	5	
Modulus of elasticity (GPa)	26.9	

3. RESULTS AND DISCUSSIONS

3.1 Confined concrete with polyvinyl chloride tubes

In general, confined concrete with a PVC tube significantly increases its Strength Enhancement Index (SEI) compared to an unconfined control sample (Eq. (1)). Specifically, the peak load capacity of samples in the group with a constant diameter of 100 mm (D1L1-2, D1L2-2, and D1L3-2) increased by 35.30%, 92.60%, and 89.60%, respectively, as shown in Figure 4(a). The lengths varied between 100 mm, 200 mm, and 300 mm, as shown in Figure 4(a). Similarly, in the group with a diameter of 150 mm (D2L1-2, D2L2-2, and D2L3-3), the increases were 18.40%, 30.50%, and 43.00%, respectively, as illustrated in Figure 4(b), when using the same lengths as the first group. The increases were 16.50%, 58.60%, and 38.10% for samples (D3L1-2, D3L2-2, and D3L3-3) with a diameter of 200 mm, as indicated in Figure 4(c), using the same lengths as the first group, compared with the unconfined samples, as shown in Table 7. Figure 5 shows the test of the specimens.

$$SEI_{PVC} = \frac{f_{cc,pvc} - f_c}{fC} \quad (1)$$

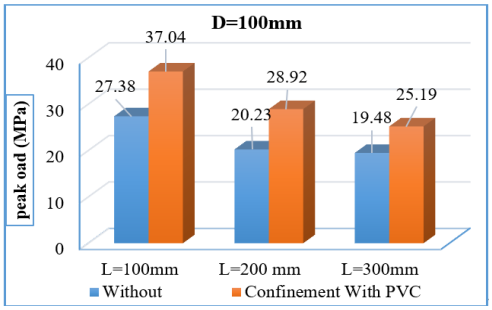
SEI_{PVC}: Strength Enhancement Index
fc: The peak of unconfined concrete by PVC
$fcc,_{pvc}$: The peak of confined concrete by PVC

Table 7. Examination results

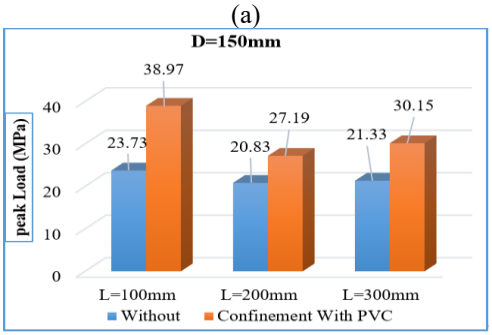
Diameter (D) (mm)	Length (L) (mm)	Thickness (t)(mm)	L/D	ID Specimen	Type of Confinement	Max Load (MPa)	SEI without PVC	SEI with PVC
100	100	2.5	1	D1L1-1	Without	27.38	/	/
				D1L1-2	Confinement With PVC	37.04	35.3%	/
				D1L1-3	PVC + 1Layer CTRC	40.44	47.7%	9.2%
				D1L1-4	PVC + 2Layer CTRC	50.18	83.3%	35.5%
				D1L1-5	PVC + 3Layer CTRC	52.5	91.75%	41.74%
	200	2.5		D1L2-1	Without	20.23	/	/
				D1L2-2	Confinement With PVC	28.92	42.96%	/
			2	D1L2-3	PVC + 1Layer	35.91	77.51%	24.2%

				D1L2-4	CTRC PVC + 2Layer CTRC	40.31	99.26%	39.4%
				D1L2-5	PVC + 3Layer CTRC	42.16	108.40%	45.8%
				D1L3-1	Without	19.48	/	/
				D1L3-2	confinement with PVC	25.19	29%	
	300	2.5	3	D1L3-3	PVC + 1Layer CTRC	28.65	47%	13.7%
				D1L3-4	PVC + 2Layer CTRC	34.12	55%	19.6%
				D1L3-5	PVC + 3Layer CTRC	34.87	79%	38.4%
				D2L1-1	Without	23.73	/	/
				D2L1-2	Confinement With PVC	38.97	64.2%	/
	100	3	0.67	D2L1-3	PVC + 1Layer CTRC	52.22	120.1%	34.0%
				D2L1-4	PVC + 2Layer CTRC	52.93	123.1%	35.8%
				D2L1-5	PVC + 3Layer CTRC	54.87	131.2%	40.8%
				D2L2-1	Without	20.83	/	/
				D2L2-2	Confinement With PVC	27.19	30.5%	/
150	200	3	1.33	D2L2-3	PVC + 1Layer CTRC	31.54	51.4%	16.0%
				D2L2-4	PVC + 2Layer CTRC	39.03	87.4%	43.5%
				D2L2-5	PVC + 3Layer CTRC	42.94	106.1%	57.9%
				D2L3-1	Without	21.33	/	/
		3	2	D2L3-2	Confinement With PVC	30.15	41%	/
	300			D2L3-3	PVC + 1Layer CTRC	34.85	63%	15.6%
				D2L3-4	PVC + 2Layer CTRC	38.93	83%	29.1%
				D2L3-5	PVC + 3Layer CTRC	43.22	103%	43.3%
				D3-L1-1	Without	25.23	/	/
				D3L1-2	Confinement With PVC	39.52	56.6%	/
	100		0.5	D3L1-3	PVC + 1Layer CTRC	47.17	87.0%	19.4%
		4		D3L1-4	PVC + 2Layer CTRC	52.92	109.8%	33.9%
				D3L1-5	PVC + 3Layer CTRC	54.74	117.0%	38.5%
				D3L2-1	Without	28.08	/	/
				D3L2-2	Confinement With PVC	37.61	33.93%	/
200	200	4	1	D3L2-3	PVC + 1Layer CTRC	42.31	50.68%	12.50%
				D3L2-4	PVC + 2Layer CTRC	46.67	66.2%	24.09%
				D3L2-5	PVC + 3Layer CTRC	55.69	%98.33	48.07%
				D3L3-1	Without	23.11	/	/
				D3L3-2	Confinement With PVC	28.11	38.1%	/
	300	4	1.5	D3L3-3	PVC + 1Layer CTRC	33.84	61.15%	16.83%
				D3L3-4	PVC + 2Layer CTRC	42.35	88.36%	36.43%
				D3L3-5	PVC + 3Layer CTRC	52.5	128.59%	65.56%

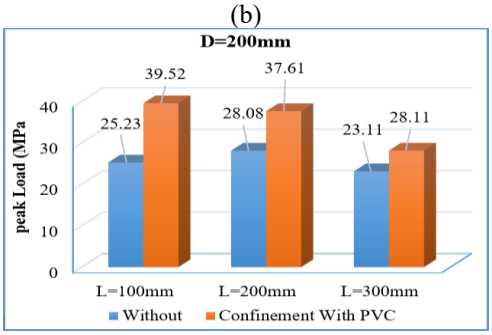
Note: Strength Enhancement Index (SEI), polyvinyl chloride (PVC), carbon textile-reinforced concrete (CTRC), length-to-diameter ratio (L/D).



(a)



(b)



(c)

Figure 4. The effect of polyvinyl chloride (PVC) confinement on the behavior of concrete: (a) diameter: 100 mm; (b) diameter: 150 mm; (c) diameter: 200 mm



Figure 5. Sample testing stages with and without polyvinyl chloride (PVC) confinement and carbon textile-reinforced concrete (CTRC) layers

3.2 Effect of carbon textile-reinforced concrete with polyvinyl chloride tube on the peak strength

The technique of adding a CTRC mesh network is a method for strengthening concrete-filled tubes to enhance their durability and resistance to applied loads when added in one, two, or three layers. Strength enhancement index (SEI) for a diameter of 100 mm and a length of 100 mm (Eq. (2)), the load-bearing strength of the samples was 35.50% and 57.90% when using one, two, and three layers of CTRC mesh, respectively, compared to the reference sample confinement with PVC; when the length is 200 mm, the results are 10.00%, 34.00%, and 35.80% when using one, two, and three layers consecutively. At a length of 300 mm, the results for the samples with different layers—one, two, and three are 23.40%, 45.30%, and 55.50%, respectively. As indicated in Table 7 and Figure 6. Also, Figure 7 shows the test results of the specimens.

$$SEI_{CTRC} = \frac{f_{CC,CTRC} - f_{cc,pvc}}{f_{cc,pvc}} \quad (2)$$

where,

SEI_{CTRC}: Strength Enhancement Index

$f_{cc,pvc}$: The peak of confined concrete by PVC

$f_{CC,CTRC}$: The peak of confined concrete by PVC and strengthening by CTRC

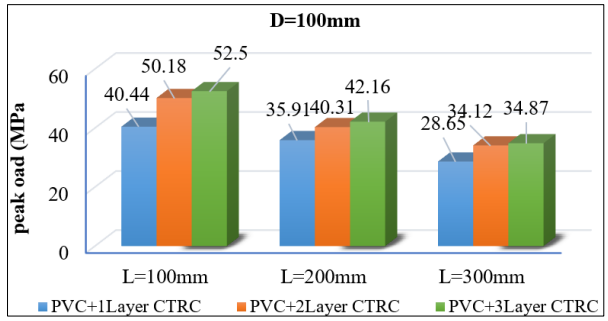


Figure 6. Effect of carbon textile-reinforced concrete (CTRC) with polyvinyl chloride (PVC) tube on the peak strength at D = 100 mm

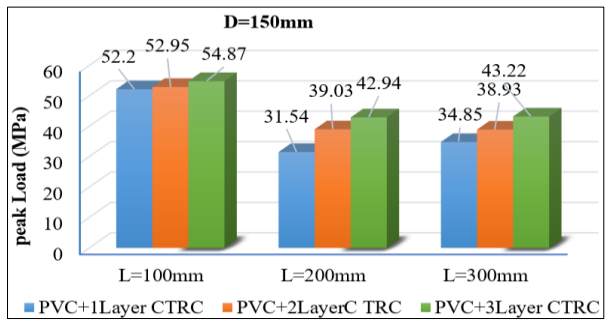


Figure 7. Effect of carbon textile-reinforced concrete (CTRC) with polyvinyl chloride (PVC) tube on the peak strength at D = 150 mm

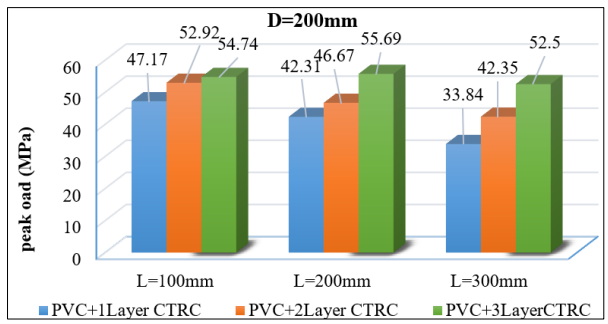


Figure 8. Effect of carbon textile-reinforced concrete (CTRC) with polyvinyl chloride (PVC) tube on the peak strength at D = 200 mm

The effect of using the first, second, and third layers of a CTRC on samples with a diameter of 150 mm and lengths of 100, 200, and 300 mm resulted in 33.90%, 35.90%, and

40.80% and 16.00%, 43.50%, and 57.90% and 24.20%, 39.40%, and 45.80%, respectively, as shown in Table 7 and Figure 7.

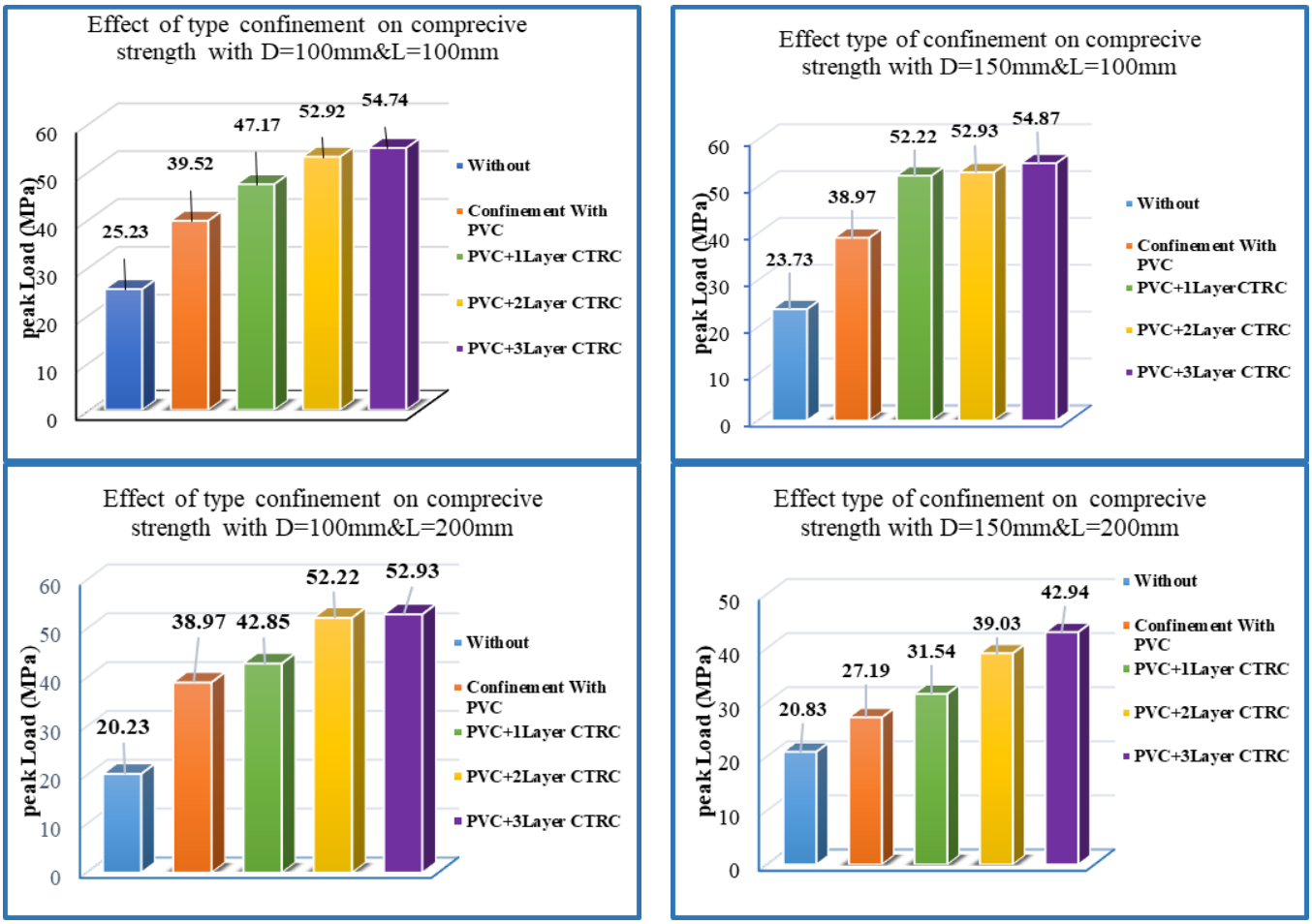
In the case of using the diameter (200 mm) with the CTRC and lengths (100 mm, 200 mm, and 300 mm), with one layer and two and three layers, the samples gave results of (19.40%, 33.90%, and 46.10%) and (18.80%, 12.50%, and 44.10%) and (16.83%, 36.43%, and 65.56%), respectively, as shown in Figure 8 and Table 7. Figure 9 shows the test stages of the specimens.

3.3 Effect of the length-to-diameter ratio on confinement and carbon textile-reinforced concrete layers

The peak load capacity of cylinders (without confinement) is inversely proportional to the L/D up to a ratio of less than 1, where it is observed that the larger the diameter, the lower the load-bearing capacity of the samples, since increasing this ratio reduces the confinement that occurs to the samples during testing between them and the machine, thus reducing their load-bearing capacity. In cases where the ratio of height to diameter is the same, the superiority tends towards the samples with the larger diameter, and this is entirely consistent with what the researchers Woldemariam et al. [36] and Ling and Chin [39] concluded. The optimal height-to-diameter ratio, which provides both strength and restriction, is 1. If this ratio is present and repeated, the larger diameter will be the stronger limiter. Similarly, a thicker tube will have a higher load-bearing capacity than its counterparts, as detailed in Figure 10 and Table 7.



Figure 9. Sample testing stages with and without polyvinyl chloride (PVC) Confinement and carbon textile-reinforced concrete (CTRC) layers



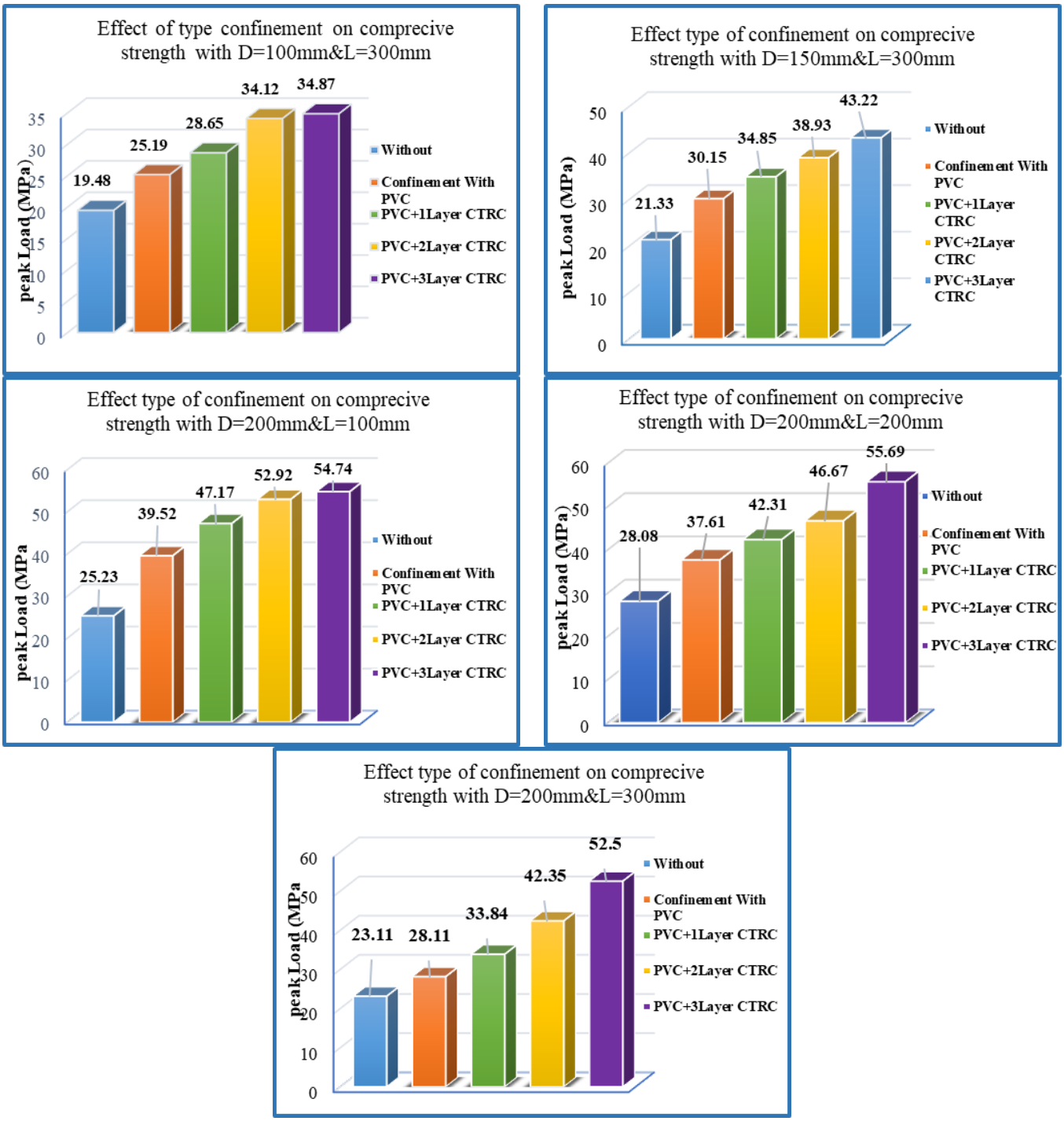


Figure 10. Results of the sample without and with polyvinyl chloride (PVC) confinement and with carbon textile-reinforced concrete (CTRC) layers

3.4 Stress-strain relation

To determine the behavior and failure patterns of confined and unconfined concrete, a strain strip was installed on unrestrained concrete and on a PVC tube for confined concrete to determine the stress-strain behavior. The stress-strain behavior shown in Figure 11(a), (b), and (c) indicates that all unconfined concrete specimens exhibit nearly linear behavior during the elastic phase before brittle failure. The presence of the PVC tube led to a transformation in the concrete's behavior from brittle to almost ductile, as illustrated in Figure 11(d), (e), and (f). Initially, the constrained concrete exhibited linear behavior, but after the plasticization stage, the line continued straight due to the tube bearing the lateral pressure of the concrete before specimen failure. However, this failure stage was not abrupt. Furthermore, the constraining of the concrete increased its strain by 38%, 45%, and 30% for diameters of 100 mm and lengths of 100 mm, 200 mm, and 300 mm, respectively. Similarly, the strain of the constrained concrete with a diameter of 150 mm increased by 94%, 39%, and 37% for lengths of 100 mm, 200 mm, and 300 mm, respectively. Likewise, the constrained concrete with a diameter of 200 mm achieved increases of 57%, 34%, and 24% for lengths of 100 mm, 200 mm, and 300 mm, respectively.

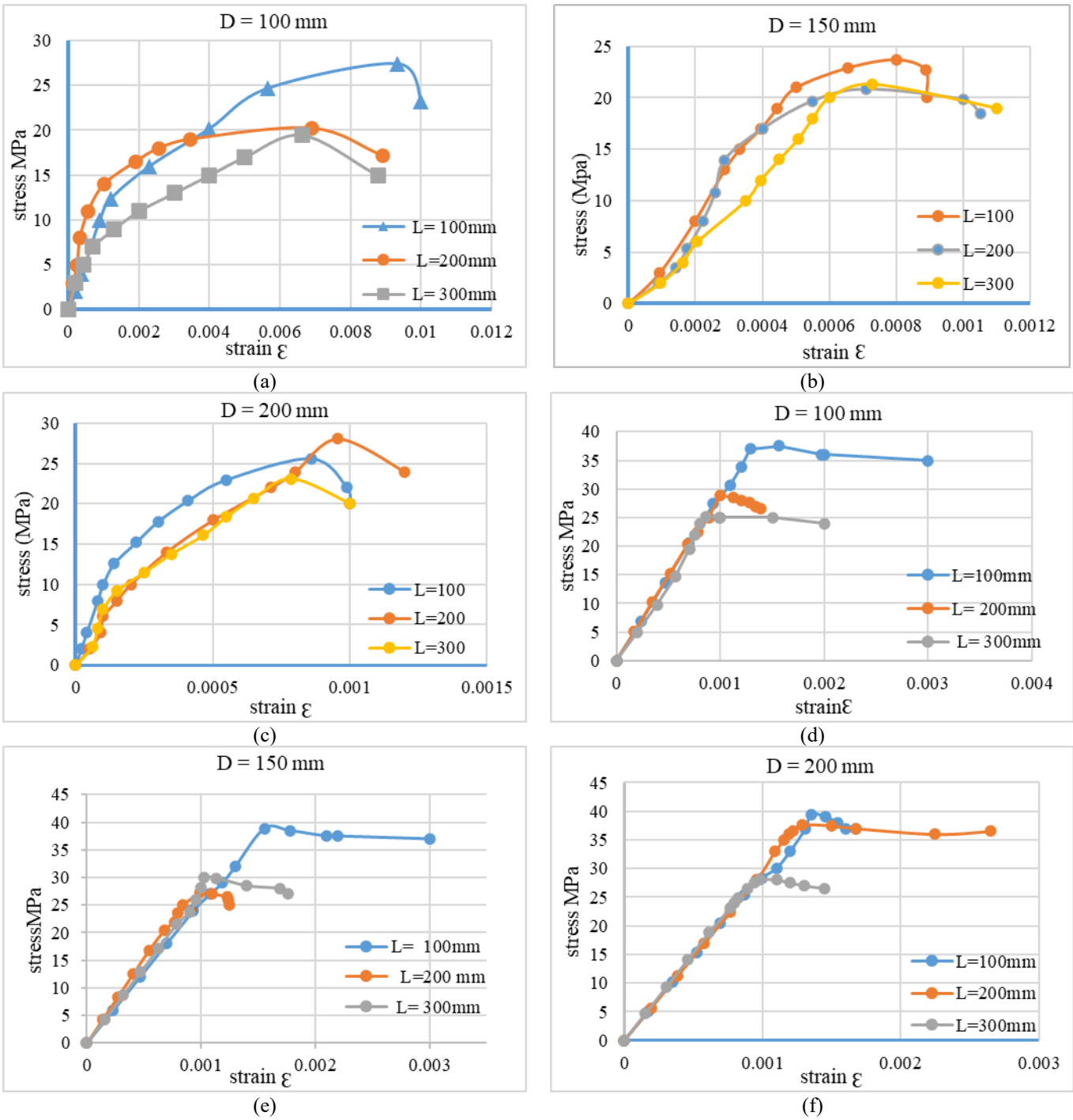


Figure 11. Stress-strain curves for (a) unconfined concrete D100, (b) unconfined concrete D150, (c) unconfined concrete D200, (d) confined concrete D100, (e) confined concrete D150 and (f) confined concrete D200

4. CONCLUSION

The following are the most significant conclusions achieved in this study:

1. The peak load capacity of concrete specimens is inversely proportional to the L/D ratio, resulting in a decrease in heaviness and a greater impact from lateral loads or lateral stresses generated by axial pressure on unconstrained cylinders. The same applies to constrained specimens; this effect occurs until the ratio reaches one.

2. When the L/D ratio is the same in the samples, the controlling factor in this case is the tube thickness and the tube diameter, as the ratio increases with an increase in either of these.

3. PVC strengthening has a significant role in providing confinement for the concrete inside, preventing its premature collapse or buckling of the specimens, as it enhances and increases the ductility of the concrete and provides confinement from a third side, in addition to confining the machine from above and below the concrete, thus improving the load-bearing capacity of all the confinement specimens.

4. When strengthening the concrete with a PVC tube using CTRC, this process provides additional confinement to the existing confinement using PVC, thus giving additional strengthening to its resistance to lateral loads generated as a result of vertical loads from the top and bottom of the

cylindrical specimens.

5. Lateral expansion resistance of specimens increases with increasing confinement, and confinement increases with increasing number of CTRC layers, and this is particularly noticeable if there is more than one layer of CTRC. It promotes making the concrete a single, confined mass from all stresses in all directions, which makes the failure of the concrete due to the materials or reaching its maximum strength.

6. When a concrete core is subjected to an axial load, it expands laterally due to Poisson's ratio, resulting in uniaxial stresses. PVC transforms the stress from uniaxial to triaxial, significantly increasing strength. Adding CTRC layers also increases the lateral stiffness of the concrete core, ensuring uniform stress distribution by providing high tensile strength that restricts PVC's transverse expansion and prevents premature PVC failure under transverse stresses. This improves stress transfer efficiency across the surface and enhances energy absorption.

7. Finally, confining the concrete and strengthening this confinement with layers of CTRC improves the strength and ductility of the specimens, thereby strengthening their weak point in resisting lateral stresses. Therefore, it is recommended to conduct a feasibility study of these strengthening techniques on reinforced concrete column samples with a length-to-diameter ratio greater than 3 and 4 to determine the extent of improvement.

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AI USAGE DISCLOSURE

AI usage disclosure: AI-assisted tools were used solely for language editing and manuscript organization. No AI tools were used to generate scientific content, data, or interpretations. The authors take full responsibility for the accuracy, integrity, and originality of the work.

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NOMENCLATURE

D	diameter
L/D	length-to-diameter ratio
OPC	ordinary Portland cement
PVC	polyvinyl chloride

RC	reinforced concrete
SEI	strength enhancement index
t	thickness
CTRC	carbon textile-reinforced concrete
uPVC	unplasticized polyvinyl chloride
w/c	water-to-cement ratio
ECC	engineered cementitious composite
GFRC	glass-fiber-reinforced concrete
FRP	fiber-reinforced polymer
CFRP	carbon fiber-reinforced polymer