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Behaviour of PVC encased reinforced concrete walls under eccentric axial loading

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ABSTRACT

Recently, polyvinyl chloride (PVC) has been used as a stay-in-place (SIP) formwork because of its lower cost compared to other materials, durability, and ease to assemble. The PVC SIP formwork used here consists of interconnected elements; panels and connectors that serve as permanent formwork for the concrete walls. In this paper, the behaviour of the PVC encased reinforced concrete walls tested under eccentric compression loading was investigated. The variables were the type of the specimen (PVC encased or control), the longitudinal reinforcement ratio (0.65% or 1.3%) and the eccentricity of the applied load. The PVC encased wall specimens showed superior performance, more ductile and higher capacity when compared to the control wall specimens. An analytical model was developed to predict the ultimate load capacity of the specimens taking into consideration the effect of the PVC on the load carrying capacity of the walls. The calculated and experimental peak loads were in good agreement.

1. Introduction

Recently, polyvinyl chloride (PVC) has been used as a stay-in-place (SIP) formwork because of its lower cost compared to other materials (such as fiber-reinforced polymers), durability, and ease to assemble. This type of formwork has been used mainly for walls in commercial, agricultural and industrial buildings. The PVC stay in place (SIP) formwork is mainly designed to be highly durable in harsh environmental conditions and to enhance the constructability and the mechanical performance of concrete.

The PVC SIP formwork consists of interconnected panels and connectors that serve as permanent formwork for the concrete walls. The panels form the outer shell of the PVC encased wall surface. The connectors slide and interlock with the panels. Panels are connected together via hollow web connectors that hold the form together as shown in Fig. 1. The hollow web connectors allow the concrete to flow laterally between adjacent cells. In addition, it facilitates the placement of reinforcing steel [6]. This system has been commonly used in casting tanks and swimming pools. The PVC encasement system may provide additional tension reinforcement and increase the confinement of the concrete, and hence increase the flexural and axial capacity of the concrete walls. When subjected to flexural load, the increase in the peak load and the ductile response depended on the wall thickness and the reinforcement ratios [3,8,11,12,13]. Under axial load, the effect of the PVC confinement on increasing the ultimate capacity depended on the configuration of the panels and the connectors [5,7,8]. For the plain concrete walls encased with PVC and tested under combined axial and flexure load, the results showed a considerable contribution of the polymer to the tensile load capacity of the specimens [4].

The PVC encased system has been used extensively to form foundation walls, retaining walls, walls in water and waste treatment tanks and walls for swimming pools. In these applications, the walls are resisting axial loads and bending moments. The main objective of this study is to investigate the characteristic behavior of the PVC encased walls with different reinforcement ratios subjected to axial compression and flexural. The behaviour of the PVC encased specimens is compared to the control specimens to assess the contribution of the PVC under different eccentricities and different reinforcement ratios which has not been addressed by existing codes. Then, a theoretical prediction is derived taking into consideration the effect of the PVC on the load carrying capacity of the walls.

2. Experimental program

Eighteen reinforced concrete walls were cast and tested at the structural laboratory at University of Waterloo. The variables in this study were the type of the specimen (PVC encased or control), diameter of the longitudinal reinforcement (10 M or 15 M rebars) resulting in reinforcement ratios of 0.65% and 1.3%, respectively, and the eccentricity of the applied load (33.9 mm, 67.7 mm, 101.6 mm). The eccentricities were proposed as ratios ($^1/_6$, $^1/_3$ and $^1/_2$) of the specimen's thickness. Six specimens acted as control specimens (without PVC encasement)

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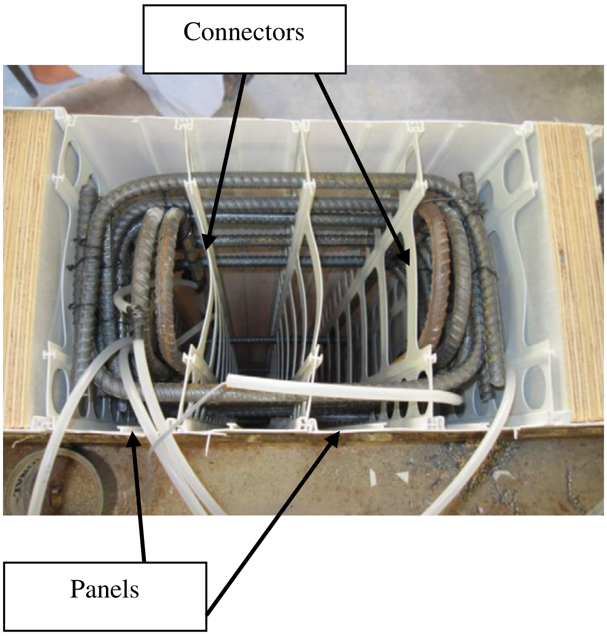

Fig. 1. Top view of a PVC encased wall.

and twelve specimens were PVC encased walls with middle connectors. The walls were cast in two batches. In the first batch, the control walls and six PVC encased walls were cast. In the second batch, the remaining PVC encased walls were cast.

All specimens had a rectangular cross section. They were 305 mm wide by 203 mm thick and 1830 mm long. The dimensions of the wall represent a strip in a wall of a tank or a swimming pool with a height that fits the testing frame at University of Waterloo. All the walls were reinforced in the longitudinal direction with 4 steel rebars (10 M or 15 M) as shown in Fig. 2. Two rebars were placed on the tension side and two rebars were placed on the compression side. In the transverse direction, two 10 M stirrups were used at each end of the wall in the first batch and five 10 M stirrups were used at each end of the wall in the second batch to increase the internal confinement and avoid end splitting. Also, the specimens were reinforced with 3 rebars (10 M) in the middle section to simulate the transverse reinforcement used in practice. The longitudinal and transverse reinforcement were tied together using spiral ties. The clear concrete cover on both the tension and the compression sides was 40 mm. Two straight coil loop inserts were used at each end of the wall specimen to facilitate lifting the specimen.

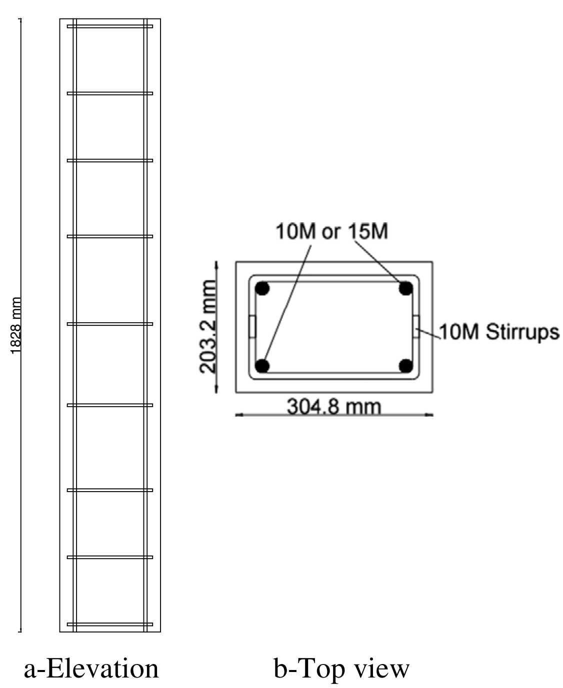

Fig. 2. Reinforcement detailing for the wall specimens.

The PVC encasement consisted of two main elements; panels and middle connectors as shown in Fig. 1. The panels were 150 mm wide and 1.2 mm thick. The middle connectors were 200 mm wide and 1.2 mm thick. Each PVC encased wall consisted of two panels on each face of the wall and five middle connectors. The PVC encased system used here is known commercially as Octaform.

Table 1 shows the test matrix. The notation is as follows; the first letter stands for the wall type; PVC encased wall (O) or control wall (C). The following letter represents the eccentricity, where e6, e3 and e2 represent an eccentricity ratio of $^1/_6$, $^1/_3$ and $^1/_2$ of the specimen's thickness (t), respectively. The last number represents the diameter of the reinforcement rebar. For instance; O-e3-15 is a PVC encased wall reinforced with 4-15 M and subjected to an eccentric compression load applied at $^1/_3$ of the specimen's thickness.

2.1. Material properties

The concrete mix had 10 mm maximum aggregate size. The slump was 170 mm to allow for sufficient flowability of the concrete to fill the cells. The average 28-days compressive strength of the concrete mix used in the first batch was 37.9 MPa and 39.2 MPa for the second batch. According to the manufacturer, the average yield strength of the 10 M and 15 M rebars was 478 MPa and 490 MPa, respectively. The average ultimate strength of the 10 M and 15 M rebars was 702 MPa and 597 MPa, respectively. According to the manufacturer, the ultimate tensile strength of the PVC was 45.9 MPa and the tensile modulus was 2896 MPa. The relationship between the strain (ε_{PVC}) and the stress (f_{PVC}) in the PVC is expressed according to Eq. (1) [13].

$$f_{PVC} = -71518\,\varepsilon_{PVC}^2 + 3412.1\,\varepsilon_{PVC} \tag{1}$$

2.2. Instrumentation and test setup

Strain gauges were mounted on both tension reinforcement and compression reinforcement at mid-span. Furthermore, 5 mm long strain gauges were mounted on the PVC panels at mid-span prior to testing on both compression and tensions sides. Also, a 60 mm long

Table 1
Test matrix.

Specimen	Connector type	Reinforcement	Reinforcement ratio	Eccentricity (mm)	Number of specimens
C-e6-10	NA	4-10 M	0.65	t/6 = 33.9	6
C-e3-10				t/3 = 67.7	
C-e2-10				t/2 = 101.6	
C-e6-15	NA	4-15 M	1.3	t/6 = 33.9	
C-e3-15				t/3 = 67.7	
C-e2-15				t/2 = 101.6	
O-e6-10	Middle	4-10 M	0.65	t/6 = 33.9	12
O-e3-10				t/3 = 67.7	
O-e2-10				t/2 = 101.60	
O-e6-15	Middle	4-15 M	1.3	t/6 = 33.9	
O-e3-15				t/3 = 67.7	
O-e2-15				t/2 = 101.60	