Energy Absorption Capacity of uPVC-Confining Concrete

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Keywords

UPVC system,
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Material damage.

Abstract

This research documents the results of tests on stub columns tested under repeated monotonic compression load. Two unplasticized polyvinyl chloride (uPVC) tubes were filled with normal and high strength concrete. From each type of concrete three control specimens were also cast for comparison purposes. The experimental test results show that the unconfined specimens were crushed in the first cycle of loading in contrast to the confined specimens which continued to resist the applied load after several cycles of repeated loading. Furthermore, by using the polymeric tube, the failure of concrete core switches from sudden explosive failure to non-brittle failure with the composite specimen undergoing large progressive deformation in each cycle of loading. For each cycle of loading, the material damage in the composite system was evaluated in terms of the deformations in both the lateral and axial directions.

1. Introduction

Thermoplastic materials find wide use in civil engineering applications [1]. One such material with good potential for structural concrete applications is the uPVC tube. With respect to its mechanical properties [2-4] and durability [5], the plastic tube displays good flexibility, toughness, and has excellent anti-corrosive characteristics [6-8]. The mechanical response of plain concrete to seismic excitation needs cyclic testing [9]. Short rectangular reinforced concrete columns were subjected to cyclically varying axial loads in order to obtain the energy dissipation capacity [10]. The cyclic stress-strain relationship of unconfined and confined concrete was established through empirical constitutive models [11]. Research has referred to the low deformation threshold for normal concrete [12]. Previous research has reported large elongations of uPVC coupons under axial tension load. A stretching of plastic samples between 40 to 100% have been documented [13-15]. Such large deformation of the plastic tube is related to its plastic flow mechanism during the axial deformations of the uPVC-concrete composite system [16]. The tube influences the peak and ultimate failure load and the corresponding peak and ultimate strains increases, too [17]. Tubular systems such as steel and FRP tubes might display good energy absorption capacity [18,19]. When these tubes filled with concrete the resulting composite system considered as an energy dissipating device. The dissipated energy is affected by the deformation mechanism and type of the tube. The polymeric tube belongs to a group of tubular structures with significant plastic deformations and energy absorption capacity [20].

An important aspect of engineering design is the mitigation of the material damage in the building components. These damages are due to the change in the service loading system under undesired circumstances. This can be achieved by containing cracks and geometric changes in the concrete core which depends on the hardening and deformation rate of uPVC systems [21]. To understand the material response of the composite system components, it's important to execute practical work to assess the energy absorbed during the plastic deformation of the composite system. The outcome of the current study enables to evaluate the influence of the loading

regime on the mechanical response of the system in terms of plastic deformations and material damage.

2. Experimental work

Experimental work was conducted to determine the axial load bearing capacity of uPVC-confined concrete. Ordinary Portland cement conforming to ASTM C150 Type I was used as a binder. Natural river sand and coarse aggregate from Eski kalak area, north of Iraq, were used throughout this research. Both the fine and coarse aggregates met the ASTM C33 requirements. The concrete ingredients were batched by weight and drum type mixer was used to mix the dry ingredients first. Water was added and mixing continued until a homogenous mix was reached at. The specimens were cast in two layers from two different mixes: C30 and C60. More details of the ingredients and concrete mixture properties are found in [22]. From each mix, one uPVC-confined concrete specimen was prepared. Concrete strength was determined by crushing three control cylinders as according to ASTM C 39.

2.1. Test setup

Before testing, all the specimens were capped with a high-strength plaster produced from a filling stone powder. The specimens were centered in the testing machine and two linear variable differential transducers (LVDTs) were used to monitor platen to platen movements of the testing machine, Figs.1 and 2. The load was applied at an average rate of 0.5kN/sec for the ascending part of the stress-strain curve. Displacement control mode was used for descending part of the curve at a compressive strain rate of (7/1000) mm/s. The confined specimens were tested under monotonic uniaxial compression load and were subjected to repeated loads and for each load cycle the peak stress and the corresponding peak strain were monitored. The accumulated strain resulted in a progressive reduction in the initial elastic modulus. When the loading platen was displaced by one-tenth of the overall length of the column the unloading of specimens was stopped and the corresponding geometrical changes were recorded.

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3. Test results

3.1. Failure modes

The specimens resisted the applied load steadily until the yielding of the tube, where the microcracks in the concrete core coalesces into macro cracks. Yielding was initiated by the plastic flow mechanism where the material undergoes permanent deformations with its microstructure suffering from atom displacement. This was evident from the white patches introduced on the surface of the tube. Table 1 shows the mechanical properties of the tube dog bones tested in tension. For the confined tested specimens, the yielding zone was located almost near the mid-height of the specimen. Beyond the yield point the specimens entered the elastic-plastic stage with the yield zone suffering further material damage.

The damage was represented by the reduction in the overall height of the specimen and continuous transverse expansion. This phenomenon was continued and aggravated when the specimen was unloaded. The evolution of elastic and plastic strains in the composite system and its relationship to material damage and eventual failure is an important aspect of repeated loading.

Table 1 uPVC tested in tension

Yield strength (0.2% offset) (MPa)	Ultimate strength (MPa)	Ultimate strain (%)
43.20	46.0	42.5

Upper loading platten fixed

Fig.1 schematic for test setup

3.2. Deformations

The specimen with overall height of 220mm, diameter of 110mm, and thickness of 7mm was placed in the center of the testing machine, Fig.2(a). The deformations undergone by the specimen is shown in Fig.2(b). As it can be seen in the first stage the specimen sustained little damage with minor changes in the shape. In the second cycle of loading the specimens exhibited considerable damage. The damage was due to the displacement ductility increasing as a result of the local buckling of the specimen and the development of additional nonlinear plastic strains, Fig.3

Figure 2. Reductions in the overall height of the specimens after first load cycle

Upper loading platten

Lower loading platten

Fig.3 the specimen with locations in the center of testing machine

Figure 4. Reductions in the overall height of the specimens after second load cycle

H=210.67mm H=210mm H=208.9mm H=207.8mm H=206.3mm

H=205.5mm H=203.9mm H=202.5mm H=200.67mm

Figure 5. Deformations in the specimen after third load cycle

H=200.67mm H=199.2mm H=198.3mm H=197.3mm
H=196.2mm H=195.1mm

H=194.2mm H=193.1mm H=192.2mm H=191.4mm H=190.7mm
H=189.56mm

Figure 6. Reductions in the overall height of the specimens after fourth load cycle

The height (H) of the specimen was monitored and regularly was measured as it can be seen in Figs.3 through 6. The test was terminated when the bottom loading platen was displaced upward by more than 20mm. The change in the original height of the specimen (220mm) was photo-graphed at regular intervals and are shown in Fig.1 to 6. As seen from the Fig.6, the specimens displayed considerable energy absorption capacity by exhibiting large geometrical changes under the applied load. In the fourth cycle of loading the specimen underwent strain hardening and it peaked at a higher load compared with the previous cycle of loading, Fig. 6.

3.3. Bearing capacity

3.4. Dissipated Energy

Fig. 7 Failure of unconfined concrete

For the first cycle of loading, the confined specimen was tested in a digital testing machine. The stub column was moved into a universal testing machine. The stress-strain relationship for the confined specimen after second cycle of loading is plotted in Fig. 8. the confined concrete undergoes minor deformations with fissures and micro-cracks initiating slowly and these increase in width and spread. the gradual increase in the applied load results in the formation of a white patch on the surface of the tube which is a sign of the tube yielding. the tube maintains its overall stability with no rupture or crack. Therefore, the ascending branch of stress-strain curve is linear up to proportional limit. Beyond the yield the curve deviates from linearity until the stub column attains the maximum strain at the peak stress. Past the peak load, the confined specimen exhibits sudden drop in the peak stress until it stabilizes. the deformations continue with minor changes in the stress until the lower loading platen is displaced vertically by 20mm.

Fig.8 Stress-strain relationship for the second cycle

3.5. Change in shape

For each cycle of loading, the changes in the shape of the specimen was monitored. This was achieved by measuring the transverse bulging of the specimen at the critical section due to the continuous concrete dilations. This was aggravated by the continuous reduction in the overall length of the tested column. The change in the shape of the specimen after each straining and unstraining cycle can be translated as a measure of material damage [11]. Fig.9 depicts the change along the height of the specimens. It can be seen that there are proportional changes in the height of the specimen after each cycle of loading. The same thing is not true for the lateral expansion, Fig.10. There is considerable energy dissipation in the third cycle of loading and to less extent in the fourth cycle of loading.

Figure 9. Reduction in the overall height of the specimens after each cycle of loading

Figure 10. Overall lateral expansion of the specimens after each cycle of loading

Conclusions

Confined and unconfined specimens have been tested in compression. The composite specimens were subjected to four cycles of repeated loads and the change in strength, peak strain and geometrical shapes were investigated. The uPVC-confined concrete specimens tested in the present work failed in compression. The failure was due to asymmetric local buckling of the tube at the critical section with almost complete damage and crushing of the concrete core. The uPVC-confined concrete specimens exhibited significant energy dissipation capacities by undergoing large deformations. The material damage of uPVC confined-concrete was reasonably expressed by the cyclic loading, which provided useful quantitative information. After each cycle of loading the residual strain increased and there was proportional reduction in the overall height of the specimens. This phenomenon was absent in the case of lateral expansion with considerable changes in the third cycle of loading followed by the final cycle of loading. There was also unproportionable drop in the peak load from first to the third cycle of loadings, 452kN, 303kN, and 285kN, whereas the peak load was increased in the fourth cycle to 325kN.

Declaration of Conflict of Interests

The author(s) declare(s) that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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