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Performance of Encased Concrete under Repeated Load

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Abstract

This study examines the behavior of UPVC confined concrete stub columns under axial compression load. Repeated loading tests were carried out on specimens loaded in uniaxial compression under varying strain and stress rates. The research aims at explaining the development of elastic and plastic strains in confined concrete and its relationship to material damage and eventual failure. The experimental results permit examining the effect of the loading regime on the composite material response, evaluated in terms of strength and deformation capacity. In addition, phenomena related to material damage were also examined. This included the deformations in the transverse and longitudinal dimensions after each cycle of loading. Experimental results show considerable deformation and energy absorption capacity for the confined concrete. A good correlation was observed between the overall reduction in length of the specimens and the corresponding overall lateral expansion.

1.Introduction

Concrete, due to its nature and inherited characteristics, is deprived of basic deformations and ductility. Testing of concrete under different loading regimes is essential to understand its mechanical performance. One such loading regime is the cyclic testing of concrete required to obtain its mechanical response when subjected to seismic excitation [1]. Strength, ductility, and absorbing and dissipating large amounts of energy are important features of cyclic testing. The behavior of plain concrete subjected to repetitions of compression load to multiple levels was examined in one of the earliest researches [2]. The authors tested forty- six short rectangular columns under cyclically varying axial loads. Other investigations have examined in detail the mechanical performance of normal concrete and concrete externally reinforced with bolts in pre-formed ducts and were either finger-tightened or torqued (pre-tensioned) to produce a lateral pre-compression in the concrete [1], or concrete internally reinforced with spiral steel [3]. Empirical constitutive models and expressions have been adopted for generalizing the cyclic stress-strain relationship of plain and confined concrete [4]. Other studies have well-established damage-plastic and fracture energy concepts for cyclic constitutive modeling [5] and served as a benchmark for exploring the nonlinear analysis behavior of structural concrete. Several attempts have been made to reduce the brittleness of concrete by introducing another less brittle material in a concrete-based hybrid system. Fibers reinforced polymers have been adopted to strengthen concrete tested under cyclic compression loading [6, 7]. These advanced materials are known to improve the strength of concrete.

One disadvantage of standard concrete is its low deformation threshold, which limits its useful ductility and further applications [8]. Concrete incorporating steel and polypropylene fibers displayed better cyclic compared with plain concrete. The blended fibers had synergetic effects on peak strength, post-peak ductility, hysteretic energy dissipation, and stiffness degradation. Another material with good potential to encase concrete and contain its induced stresses is unplasticized polyvinyl chloride (UPVC) [9]. This polymeric material, with economic advantages, exhibits considerable elongation at ultimate load [10]. The plastic tube encasement may convert concrete into a composite, offering considerable seismic resistance [11]. Previous studies have shown that UPVC-confined columns tested monotonically offered greater strength and significantly larger ductility than specimens not confined with plastic tubes [12]. Tests on UPVC confined-concrete under uniaxial cyclic compression have not been carried out before, and the present study is an attempt to handle this issue.

2. Experimental program

2.1. Materials

Eski kalak valley limestone gravel was used as a coarse aggregate. The fine aggregate was the sand river from the same source. Ordinary Portland cement was used to bind the concrete ingredients, which were thoroughly mixed using an electric mixer until a homogeneous color of fresh concrete was achieved. Two mixes (groups) were prepared with a target concrete compressive strength of 30 and 60MPa and tube thickness of seven and five millimeters, respectively. From each mix, two UPVC-confined concrete and three unconfined concrete were cast.

2.2. Testing

The specimens were loaded in a universal testing machine at a compressive strain rate of (7/1000) mm/s. Instrumentation consisted of vertical transducers to record the axial displacements of the column (Fig. 1). Four UPVC confined concrete stub columns were subjected to a small number of complete load cycles, with the maximum load attained in each cycle inferior to the load reached in the next cycle or exceeding. The increase in the previously applied strain results in a progressive reduction in the initial elastic modulus. Loading and unloading were carried out steadily. At the maximum load of each cycle, time was taken to read the instruments. Unloading of each cycle was discontinued when the lower loading platen was vertically displaced by approximately one-tenth of the length of the specimen. At the end of each cycle of loading, the specimen was removed temporarily to compute the overall reductions in lateral and longitudinal directions.

Figure 1. Set up and testing of specimens

The stress-strain curves of the tested specimens were plotted in Figs. 2 through 5. For the first cycle of loading, the specimens were tested in a digital compression testing machine. As shown in Fig.2, the damage in the concrete core is gradual with initiations of micro-cracks which increase in size and number as the load approaches the yield load of the tube. As shown in the first photo in Fig.2, the tube remains intact at half of the ultimate the concrete continues to deform and the microcracks coalesce into macro cracks, and the tube starts to yield; a white patch is formed on the surface of the tube. After the yielding of the confining tube, the stress-strain response deviates from linearity until the specimen reaches maximum strain at the peak stress. Beyond the peak load, there is no falling branch of the stress-strain curve because of the unloading process, where the stress drops rapidly and cracks close. For the second cycle of loading, the specimen was removed. The overall reductions in specimen height and increase in the lateral expansion of the specimen were measured before transferring the

3. Discussions of test results

3.1. Stress-strain curve

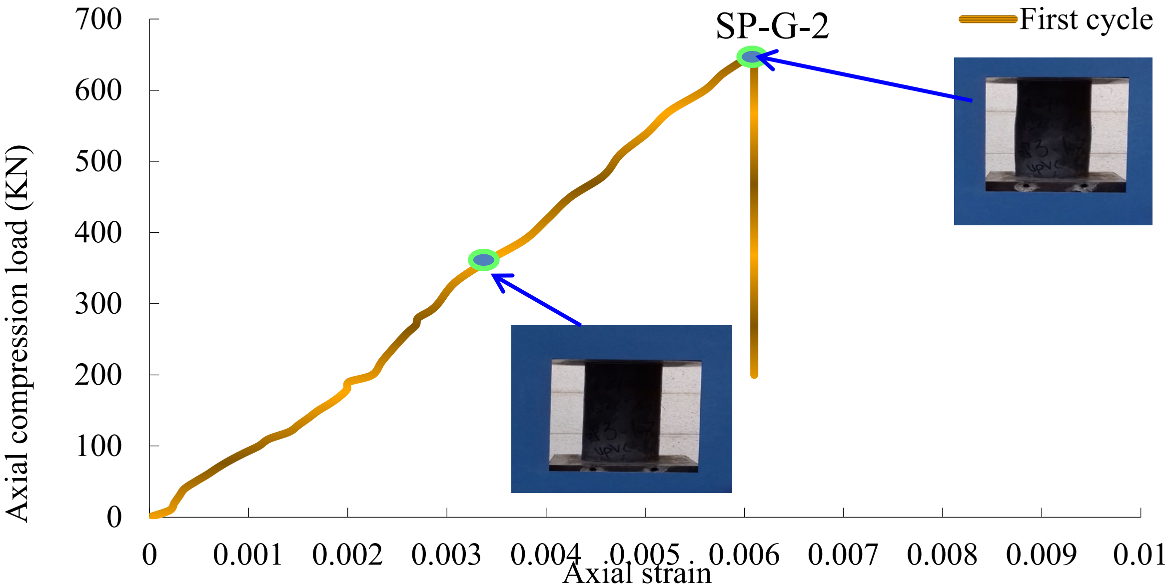

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Figure 2. Load –strain relationship for UPVC-confined concrete after first cycle of loading

specimen to a universal compression testing machine, Fig.1. As shown in Fig.3, the loading was graduate with an elastic stress-strain response, nearly a straight line up to the previous cycle yield point. At this stage, the deformation in the specimen is internal with the concrete core deformations contained by the confining tube, where cracks reopen and the tube deforms; the yielded area of the tube increases in size. The specimen continues to resist the applied load, but it peaks at a load value lower than that for the first cycle by nearly one-third.

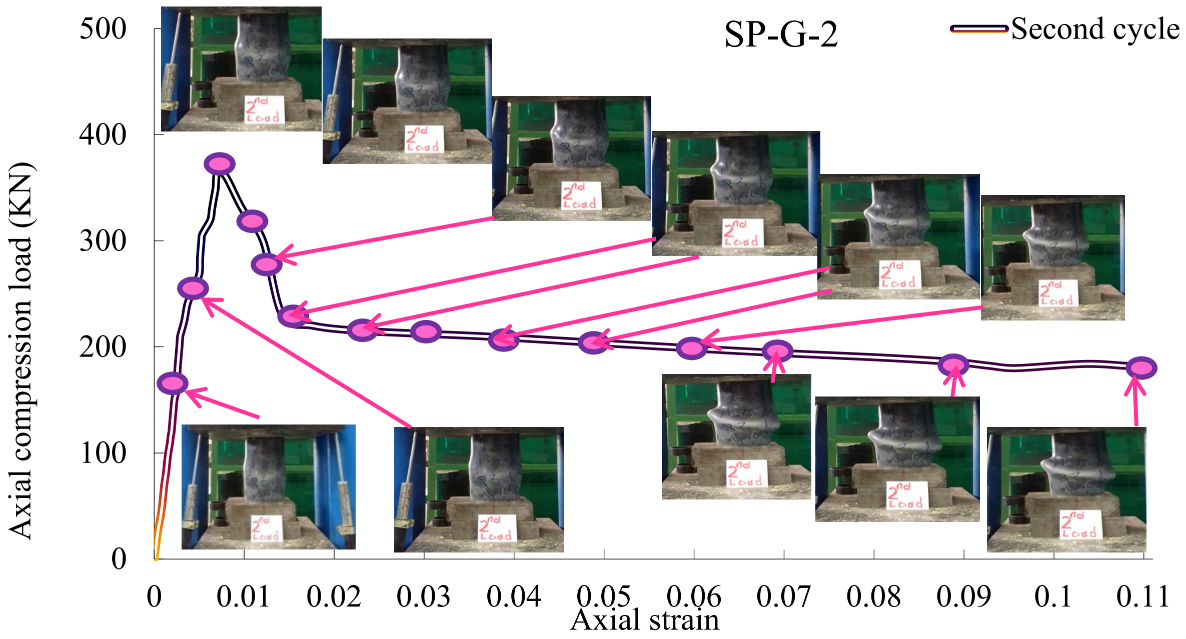

Figure 3. Load –strain relationship for UPVC-confined concrete after second cycle of loading

Beyond the peak load, the specimen exhibits compression softening where the stress drops with an increase in strain. The test was stopped when the overall reductions in the height reached 10%. Fig.3 illustrates the typical damage and deformation sustained by the UPVC-confined concrete specimens after the second loading cycle. The deformation in the specimen was photographed at regular intervals of loading, Fig.3. As seen from the photos, there are considerable deformations in the specimen, where the overall height decreases and the corresponding lateral expansion increases. The stress-strain response of the specimen in the third cycle, Fig.4, was similar to the second cycle but with a slight drop in the elastic stiffness for the ascending curve.

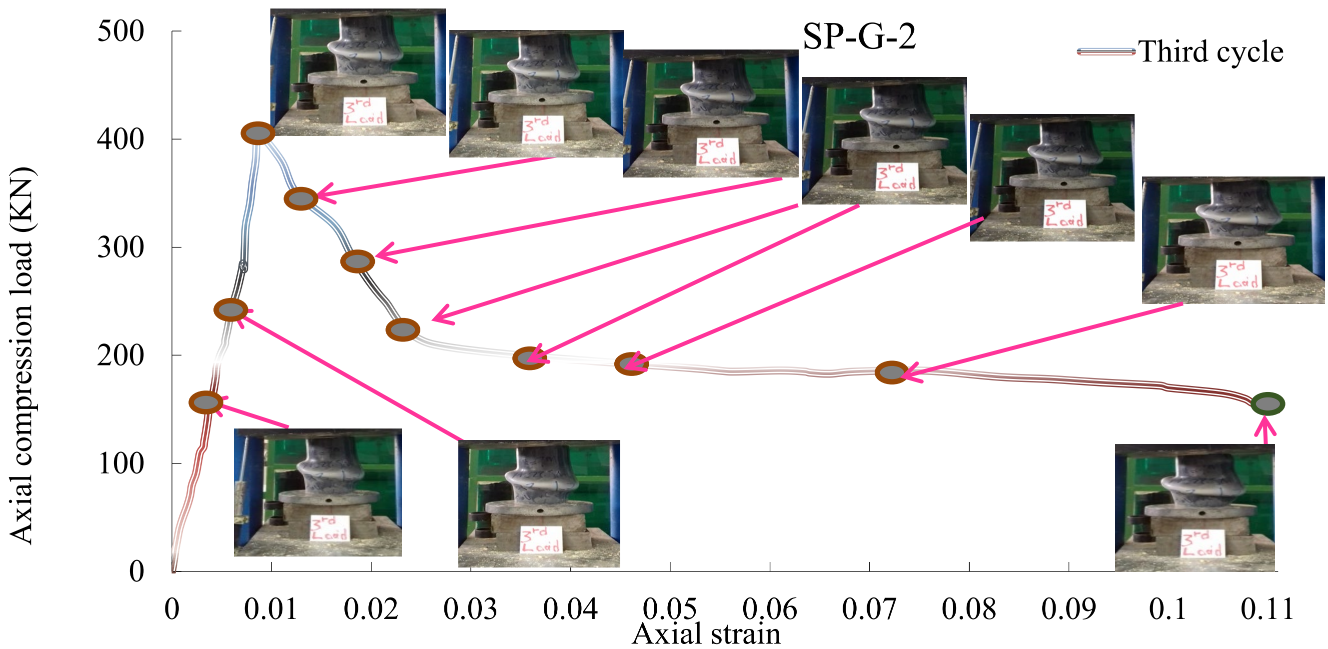

Figure 4. Load –strain relationship for UPVC-confined concrete after third cycle of loading

Furthermore, the peak load was higher than that for the second cycle, which could be ascribed to the strain hardening in the tube. The yielded area of confining tube increases in size, and its buckling increase as the load increases. Similar behavior is observed for the specimen in the fourth cycle with a negligible drop in the peak load, but the elastic stiffness continued to degrade, Fig. 5. The cycling regime did produce a significant change of load-carrying capacity after each cycle of testing. The strain at maximum load changed considerably, which can be attributed to the flexibility of the tube. During cycling loading, higher values of ultimate strains were attained. This enhanced strain behavior is ascribed to cumulative damage of the concrete core and elongation of the tube at ultimate load.

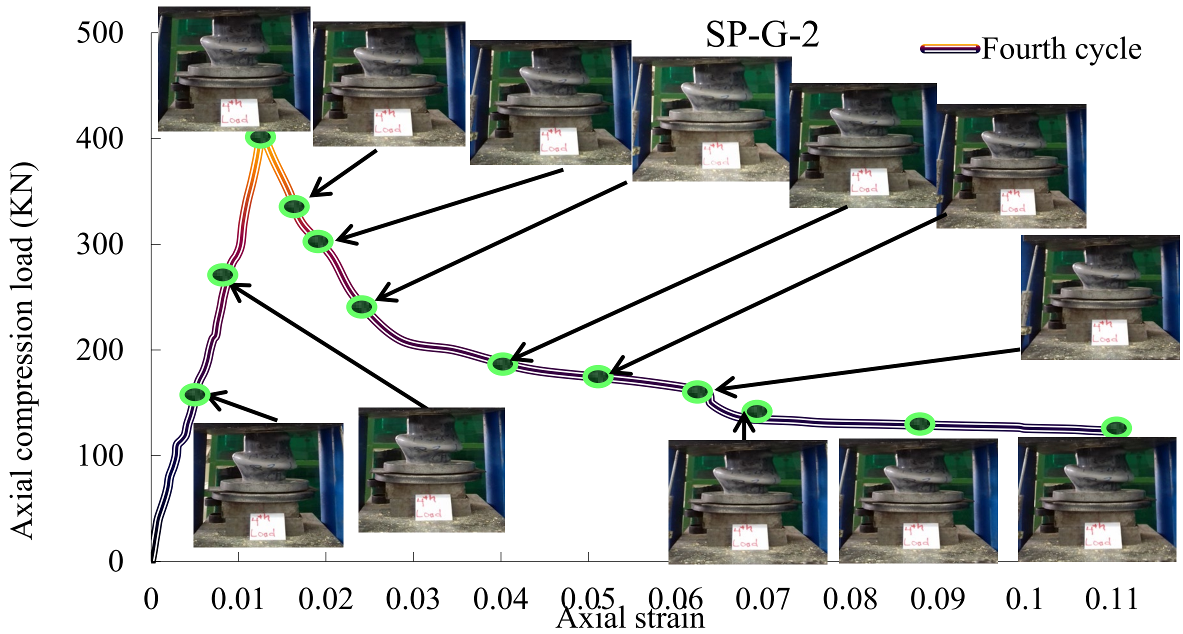

Figure 5. Load –strain relationship for UPVC-confined concrete after fourth cycle of loading

3.2. Strength

The specimens were compressed monotonically. For the concrete with a target strength of 30MPa (group two), the mean maximum load of the UPVC-confined specimens was 452kN after first loading. However, a substantial deterioration in strength was noticed in the strength beyond cycle one because of the propagation of cracks, and the ultimate load was reduced to 303kN in the second cycle of loading. The peak load further deteriorated to 285KN in the third cycle. However, in the fourth cycle, the ultimate load upgraded to 325KN. Cracks inclined to the direction of loading which had formed in previous load cycles close up under the applied pressure yielding increment in loading capacity of the column. Further, the discussion of the capacity in compression falls outside the scope of this study.

3.3. Composite action

A part of the damage happens during the application of the first cycle of load, where micro-cracks cracks are generated. With repeated cycles of loading, micro-cracks propagate. The confined material undergoes continuous changes resulting in further damage of the concrete core, which disintegrates into broken lumps and individual particles. In the fourth cycle, the plasticization of the plastic tube results in strain hardening, increasing the specimen's strength. The composite action between the tube and concrete core is further damaged, and additional nonlinear plastic strains develop. In the end, the composite between the tube and core is lost, and the individual particles of disintegrated concrete suffer further damage converting into dust.

3.4. Energy absorbed

A significant amount of energy was dissipated by the tube in each cycle of compression loading, depending on the amount of damage sustained by the specimen. The objective of the stress-strain curve, following straining and un-straining cycles, is to obtain the damage accumulation and the energy dissipation of the UPVC-confined concrete due to cyclic loading. For confined specimens, the energy dissipated by cycle load can be regarded as a measure of damage due to fracture within the concrete core when the specimen experiences a particular deformation for the first time but not subsequently. A hysteresis loop is produced in the stress-strain curve when energy is dissipated during straining and un-straining. The amount of nonrecoverable damage in the specimen after each cycle furnishes the final shape of the unloading and reloading curves. The behavior of specimens with relatively small strength decay corroborates the logicality of the use of polymeric tubes for large deformations. In contrast, it was not possible to trace the cyclic stress-strain response of unconfined concrete because of its brittle behavior.

3.5. Stiffness degradation

Nonlinear behavior of UPVC-confined concrete includes yielding, cracking of core concrete, axial shortening, lateral expansion, compression softening, and compression stiffening or plasticization of the polymeric tube where cyclic straining and un-straining introduces other phenomena's such as stiffness degradation in concrete and the tube. The behavior of the specimen in the first cycle of loading was different from the other cycles. In the first cycle of loading, a continuous decrease in stiffness was observed. The next cycle of loading displayed a smaller reduction in the value of stiffness, where the slope of the unloading branch decreased.

3.6. Tube thickness

The confining tube has a vital role in improving the cyclic behavior of the concrete core in terms of peak strength, post-peak compression softening, hysteretic energy dissipation. The tube thickness can yield a remarkable reduction in plastic strain accumulation. The stress deterioration ratio and the stiffness deterioration ratio can be significantly enhanced than those not confined, which offers no resistance to degradation. The dissipating energy capacity is somewhat less sensitive to the variations of tube thickness than the concrete strength.

3.7. Geometrical changes

Several studies regarded reducing the height of a specimen observed after several loading cycles or straining as a measure of damage [4]. The reported results of overall length reduction can be of sufficient accuracies, and it's a valuable measurement of the structural damage of the specimen under cycle loading, Figure 6. Correlation equations that relate the overall reductions in height with the general transverse expansions were formulated. These equations show a good measure of material damage after cycling load is the overall change in the height of the specimen in combination with the lateral expansion of the specimens to dissipate the absorbed energy.

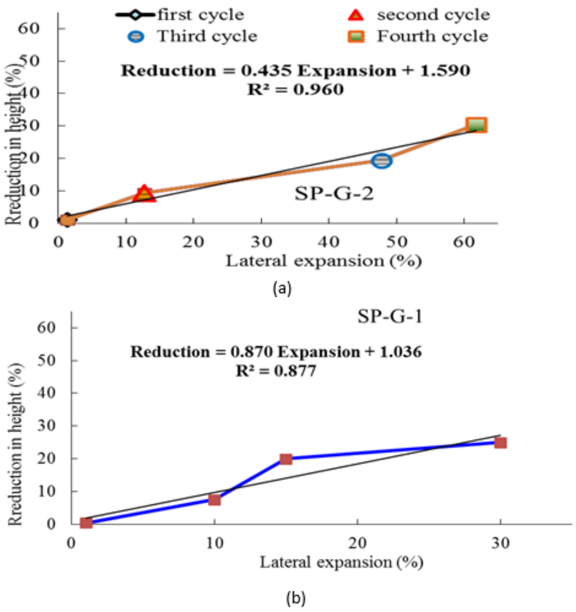

Figure 6. a) Overall reduction in height of specimens versus lateral expansion after each cycle of loading, group two b) Overall reduction in height of specimens versus lateral expansion after each cycle of loading, group one

4. Concluding remarks

The following conclusions are drawn;

The UPVC-confined concrete specimens exhibited significant energy absorption and dissipation capacities. The confined specimens were deformed mainly under the effect of the dissipated energy. Damage energy becomes considerably noticeable after the initiation of tube yielding. At the end of an unloading cycle, the residual strain increases. Correlation equations that relate the overall reductions in height with the overall transverse expansions were formulated. These equations show a good measure of material damage after cycling load is the overall change in the height of the specimen in combination with the lateral expansion of the specimens to dissipate the absorbed energy. The reduction in the integrity of UPVC confined-concrete specimens during straining and unstraining was sufficiently expressed by the cyclic loading, which provided useful quantitative information.

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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