POST FAILURE REPAIR OF SELF-REINFORCED CONCRETE BLOCK PRISMS

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ABSTRACT
In order to produce concrete block construction capable of sustaining very high compressive strains without loss of compressive strength, a new block type, Self-Reinforced Concrete Block (SR Block), has been developed. These blocks utilize devices molded into the solid body of hollow block during manufacture. Under axial compression, these devices provide lateral confinement of the volume of block, bed joint mortar, and grout in the cells of the hollow block enclosed within the devices. As reported elsewhere [1], when tested in four-course high prisms, at strains slightly greater than found at failure of normal block prisms, the parts of the blocks external to the confining devices begin to spall off. The enhanced strength of the triaxially compressed volume within the devices result in no loss of prism capacity until strains several times larger than the normal crushing strain of concrete block masonry are reached. This behaviour allows masonry to achieve improved levels of ductility leading to economical design of reinforced masonry to withstand seismic loading.

When the capacity of the confined materials is utilized, the compressed masonry is left in a visibly damaged state due to the spalling of the unconfined part of the compression zone. This paper reports on research where previously tested prisms are repaired by casting new concrete/grout around the remaining confined volumes after any loose material has been removed. This simple and low-cost repair procedure restores the initial high stiffness of the concrete block masonry under compression to regain expected serviceable performance under service loads.

KEYWORDS: concrete block, confinement, ductility, masonry, repair, seismic performance

INTRODUCTION
Use of the beneficial effect of lateral confinement within reinforced concrete columns is a common practice, where internal spiral or hoop reinforcement has been shown to increase the strength and ductility of the column [2,3]. This confinement triaxially compresses the concrete within the reinforcement, maintaining its strength when spalling of the exterior surface shell concrete occurs [2,4]. However, a potential problem arises in the need to restore the structure to

its original strength and ductility characteristics following an occurrence of expected damage resulting from ductile response to seismic loading. Typical intensive repairs or full demolition of damaged structures are costly procedures, which can negatively influence the adoption of methods to achieve ductility.

One method presented for repair of moderately damaged reinforced concrete columns, those with cover concrete spalling and longitudinal reinforcement yielding, is "cover concrete patching" [4] in which low slump concrete is hand applied to spalled areas of the column. This method suggests that alternative methods of recasting concrete could also be used for repair.

In this research, a new laterally confined concrete block, SR Block, was used to construct prisms representing the end compression zones in masonry shear walls. The program involved axially loading the prims to peak loading capacity and then repairing the damaged regions in a similar manner to a reinforced concrete column. The repaired prism was subsequently tested for restored strength performance from the resumed loading strain to end failure strain. The ability to achieve the originally observed high strains without loss of capacity is related to situations where high compression strain might be required again in the event of a subsequent earthquake. This characteristic is evaluated through retesting to a similar strain extreme.

EXPERIMENTAL TEST PROGRAM

The SR Blocks were fabricated as 20 cm splitter blocks with a 142 mm diameter cell. The confining devices were inserted into the mold of an automated block-making machine. As indicated earlier [1], for blocks with smaller cells, placement of the devices and full compaction of the concrete in the molds were accomplished very satisfactorily. As displayed in Figure 1, the confining devices were manufactured from 11-gauge steel. The designed device is 164 mm in diameter (centre-to-centre), 184 mm in height and has 19.1 mm openings spaced 6.3 mm apart in all directions. The yield strength of the steel was measured as 401 MPa.

Figure 1: Lateral Confining Device

The SR Block prisms were built on site by a qualified mason in the Applied Dynamics Laboratory of McMaster University. As shown in Figure 2, the prisms were four courses high and one block long, with a one-half running bond. Each prism was grouted with fine grout mix prepared in the laboratory having a slump of 270 mm. The material properties and mixes are given in Tables 1 and 2, respectively. Prisms one and two were grouted with mix ~~-~~#1, while prism three was grouted with mix # 2. Subtracting 1.64 times a minimum coefficient of variation of 10 percent from the average values shown in Table 1 results in specified block, grout cylinder, and mortar cube strengths [5] respectively of 23.9 MPa, 20.6 MPa, and 11.5 MPa.

Figure 2: Typical Prism Specimen

Table 1: Material Properties

Material	Mean Strength (MPa)	C.O.V. (%)	Yield Strength (MPa)
Block	28.6	4.0	-
Mortar (Cube)	13.7	1.4	-
Grout #1 (Cylinder)	26.5	3.4	-
Grout #1 (Cell-Molded)	34.3	3.0	-
Grout #2 (Cylinder)	22.8	3.0	-
Grout #2 (Cell-Molded)	30.6	3.3	-
Steel (device)	560	-	401

Table 2: Mix Weight Ratios

Mix	Cement	Lime	Dry Sand*	Water
Mortar	1	0.21	4.39	0.95
Grout	1	0.04	4	0.85

*Masonry sand was used for the mortar whereas concrete sand was used for the grout.

The three prisms were tested under monotonically increasing, displacement controlled, concentric axial loading at a rate of approximately 0.9 mm per minute. Displacement controlled loading allowed more data points to be collected during failure of the surface shell concrete and subsequent continued loading of the confined cores. A 76 mm thick, steel capping plate was attached to the bottom and top of each prism with an even three mm spread of Hydro-Stone gypsum cement to ensure uniform load distribution and to facilitate specimen placement into the test machine.

Each prism was instrumented with four string potentiometers (one per side) to measure strain over the central 600 mm of the prism height. Four additional string potentiometers, one per side, were used to measure the strain over the full height of the prism once cracking and spalling rendered the on-prism instrument output unusable. Load and displacement readings were taken during the entirety of the test at a rate of 2 Hz using a data acquisition system. The on-prism potentiometers were removed prior to face-shell spalling, but after initial failure, in order to prevent damage to the instrumentation. Loading was terminated at the earlier of the second loading peak or 2% strain as will be discussed later.

Each prism was then carefully removed from the test setup. The steel loading plates were removed along with any concrete that could be easily freed. The resulting specimens were then laid flat in a plywood form sized to the dimensions of the original thickness and length of the prism. The displaced height after the first test was preserved. The specimens are shown in the forms in Figure 3(a) prior to repair grouting. This photograph also indicates the typical degree of spalling associated with having achieved a compressive strain of near 2%.

Previous work by Atkinson and Schuller documented the use of expansive admixtures to ensure minimal plastic shrinkage of repair grout [6]. Consequently, Type GU cement was replaced with Type K expansive cement to compensate for drying shrinkage. Additionally, Sika Intraplast-N admixture was used, in the amount of 1% by weight of cement. The admixture contains fluidizing agents to ensure thorough filling of the forms and around the spalled specimens. This admixture also included an expansion agent to compensate for plastic shrinkage of the grout. As shown in Figure 3(b), the three specimens were repaired on the same day with the above mentioned grout mix having an average cylinder compressive strength of 22.1 MPa. The repaired prisms were tested to the same specifications as the original prisms, except that loading was continued to extremely high strains until complete failure occurred.

(a) Tested SR Block Prisms Positioned in Forms in Preparation for Repair

(b) Prisms Shown After Completion of Repair Grouting

Figure 3: Photographs of Repair of Test Prisms

TEST RESULTS

The failure patterns for each of the original three prisms were consistent. Each prism reached an initial ultimate strength corresponding with the beginning of failure of the surface shell of concrete block outside of the confining devices. The average initial peak strength was 14.7 MPa, as shown in Table 3, and this occurred at an average strain of just over 0.2%. At this point, the load rapidly decreased to a plateau of approximately 13.2 MPa before it began to increase again. This pattern of load drop then increase is due to the lateral confining device surrounding each cell. With cracking and then spalling failure of the outer shell of concrete block, the load decreased due to the loss of cross-section area. This was mitigated to a large extent by the concrete block and grout within the self-reinforcing device already experiencing some benefit from its confinement, even at the comparatively low axial compressive strains in the range of 0.2 to 0.3%. As axial compression strain increased, the resulting lateral compression against the confinement device produced a corresponding increase in vertical compressive strength related to the state of triaxial compression. This enabled each prism to exceed the initial ultimate strength reached prior to failure of the unconfined region. Not only did the considerably reduced cross-sectional area regain its initial peak, full section capacity, but the confined concrete and grout reached an average secondary ultimate strength of 17.4 MPa, as shown in Table 3, at an average strain of approximately 1.6%. These results indicate an 18.4 % increase in strength during an increase in strain of a factor of approximately 6.4.

Table 3: Original Prism Test Results

Prism	Peak Stress (MPa)*	
	Initial	Secondary
1	13.4	17.9
2	15.0	16.9
3	15.7	17.5
Average	14.7	17.4
C.O.V. (%)	8.0	3.0

*Based on full gross prism area of 74,100 mm^2

The repaired prisms exhibited two distinct failure modes. Two of the prisms reached their ultimate strength at the time of failure of the repair concrete/grout with no subsequent load gain. The third repaired prism behaved somewhat similarly to the original prisms with two distinct peaks. However, unlike the original prism tests, the second peak did not quite reach the initial capacity. A factor in this difference may be related to Prism #3 having been loaded to a slightly lower maximum strain during the initial test prior to repair. The results are presented in Table 4.

Table 4: Repaired Prism Test Results

Prism	Peak Stress (MPa)*	
	Initial	Secondary
1	24.3	-
2	21.3	-
3	20.5	19.9
Average	22.0	-
C.O.V. (%)	9.0	-

*Based on full gross prism area of 74,100 mm^2

Failure of each repaired prism was observed to start with vertical cracks forming in the centre two courses, but this cracking propagated to span nearly the entire prism height as the prism was subjected to the increasing vertical strain. The sides of the prisms were the first zones where the repair concrete/grout began to spall, exposing the confining device underneath. As seen in Figure 4, some areas of repair remained intact along the faces of the prisms even at very high strains corresponding to evident bulging of the confining devices.

Figure 4: Repaired Prism #2 at Midtest

Figures 5, 6, and 7 contain plots of the stress-strain curves for tests before and after repair for the three test prisms. As can be seen in all cases, the repairs effectively restored the initial high stiffness of the grouted concrete block prisms under compression loading. The repaired prisms consistently were able to exceed the capacity of the original prisms and maintain equally large strains. This improved behaviour was unexpected. The average strength of the repaired prisms was approximately 50% greater at initial failure compared to initial failure of the original prisms. As can be seen in Figures 5 to 7, the strength of the repaired prisms gradually decreased until they converged with the stress-strain curves of the original prisms. This occurs at an average strain of about 1.6% corresponding to the second peak point at which original testing of the prisms was terminated. This intersecting phenomenon corresponding with the very high spalling strains indicates that the repaired prism has returned to its original damaged condition sustained at termination of the original tests. However, it should be pointed out that at the end of the original tests, the residual compression strain in these prisms averaged 1.4% so that total accumulated compression strain is the value shown in the figures plus the residual strain. The ability of the prisms to be repaired and remain stable again following application of new high compression strains is attributed to the lateral confining devices within the blocks continuing to effectively confine the enclosed parts of the cross-section.

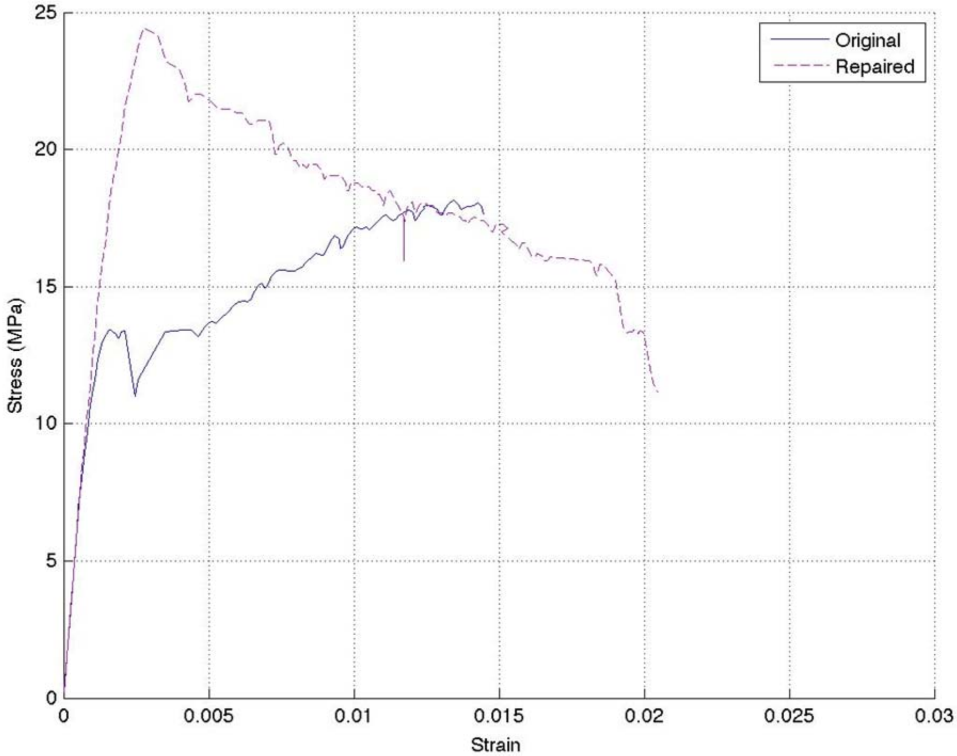

Figure 5: Stress-Strain Curves for Prism #1

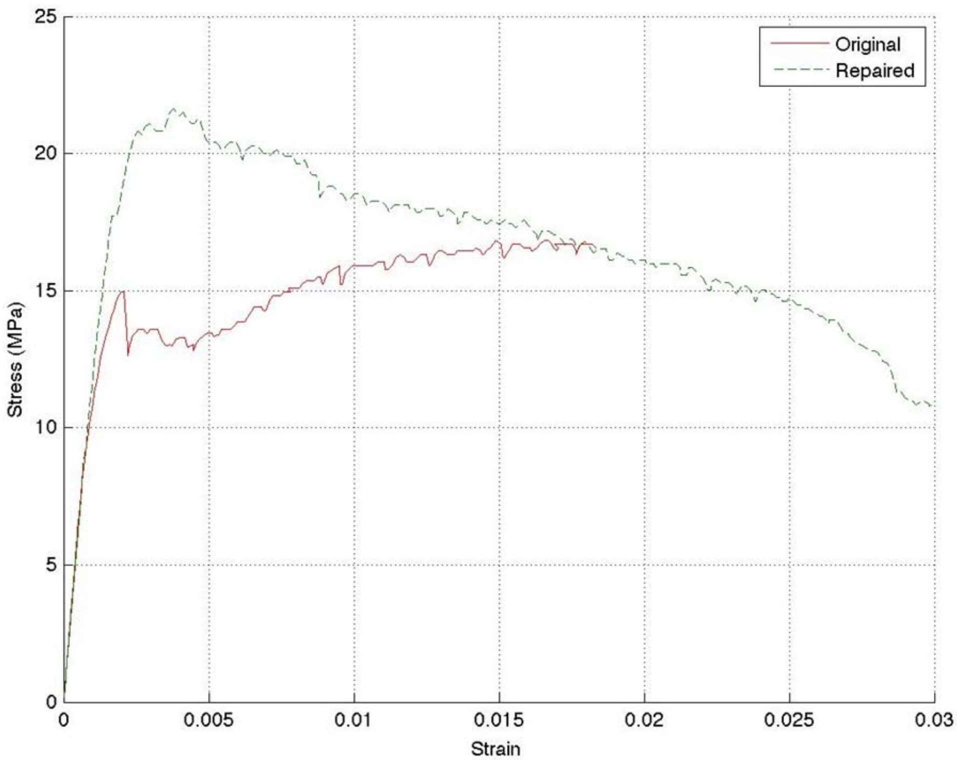

Figure 6: Stress-Strain Curves for Prism # 2

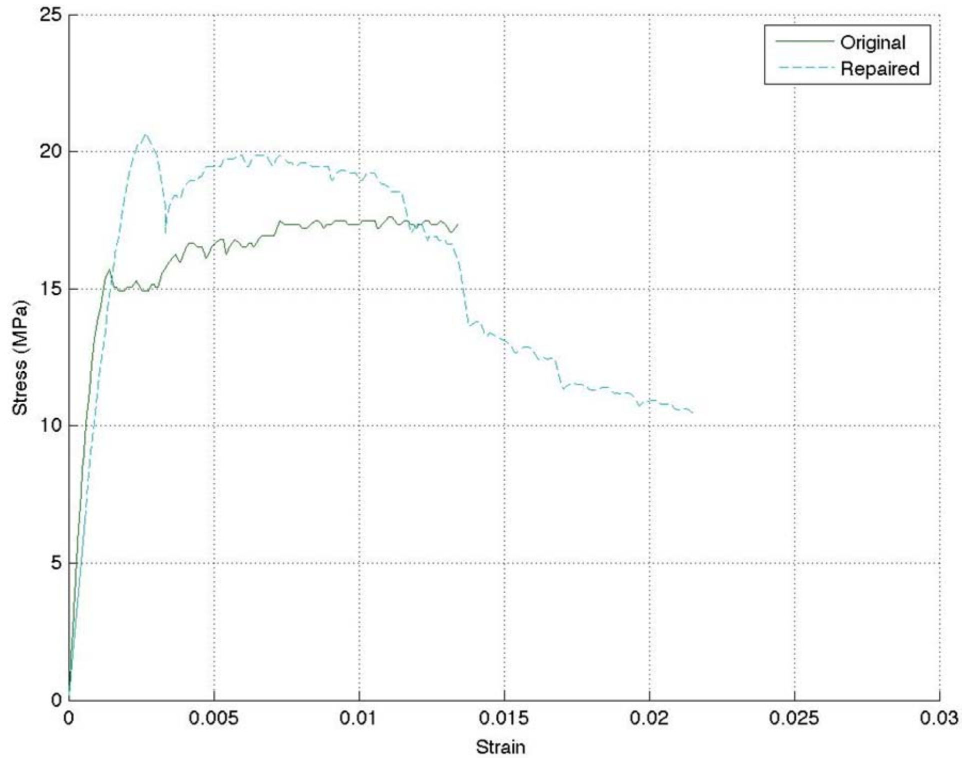

Figure 7: Stress-Strain Curves for Prism #3

SUMMARY AND CONCLUSION

A new hollow concrete block type called Self Reinforced (SR) Block, containing tubular punched steel confining devices, was used to construct four-course high prisms. After filling the cells with grout, these prisms were subjected to compression testing to the point of reaching secondary peak loads corresponding to very high strains and spalling of the prism region not contained within the confining devices. At this point they were unloaded and repaired by casting expansive concrete/grout around the remaining intact concrete core. These repaired prisms were then retested to investigate the ability to restore initial stiffness, strength and ductility following loading representing an extreme seismic event.

The prism test results allow the following conclusions to be drawn:

a) In their original condition, grout filled SR Block prisms provide increased compressive capacity at strains up to about 1.6% corresponding to conditions where regions of the prism not contained within the confining devices have failed due to spalling.
b) After loading the prisms to produce the above damage state, restoration of the prisms to their original dimensions was easily carried out by constructing forms and pouring grout into the forms.
c) Tests of the repaired prisms demonstrated that the initial high stiffness of the concrete block masonry was fully restored.
d) Although the repair grout was not especially strong, the initial peak strength was substantially greater than either the corresponding initial peak strength or the higher secondary peak strength of the original prism tests.
e) The stress-strain curves of the repaired prisms converge to the original curves, at a strain

corresponding to the second peak strength of the original prisms. This indicates that the region within the confining devices remained capable of maintaining high strength during reloading to a damage state similar to the original loading.

~~a)~~f) Overall, it is suggested that use of SR block to achieve high ductility in reinforced masonry has the further advantage of simple and economical repair following loading to take advantage of the inherent ductility.

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