Confinement effects and strain transfer in reinforced concrete jackets of different detailing for the strengthening of old-type concrete columns

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SUMMARY:
The study concerns the mechanical behaviour of 5 reinforced concrete columns with dimensions 150x150x750 mm height, strengthened by a thin 40 mm steel reinforced jacket using cast-in place self-consolidating concrete. Steel reinforcements in as-built columns were smooth and low quality to simulate old type columns with inadequate detailing. The columns were designed in 1:2 scale while they address the viability of the application of cast-in place thin jacket instead of shotcrete. The columns varied by the common measures taken in practice to restore the monolithic behaviour of the jacketed columns. The columns were subjected to axial compression cycles of increasing displacement. The mechanical behavior of the columns was assessed through their stress versus axial strain curves. Experimental results showed that the enhancement of strain ductility of the existing column confined by rc jacket was remarkable.

Keywords: confinement, concrete jacket, self-consolidating concrete

1. INTRODUCTION

Reinforced concrete jackets have been extensively examined (Rodriguez & Park 1994, Stoppenhagen et al.1995, Vandoros & Dritsos 2006, 2008) and are widely used in strengthening of existing concrete members. Shotcrete jacketing technique, while more demanding, is often used for thin concrete jackets with width lower than 10 cm. On the other hand, poured concrete jacketing usually requires a minimum jacket thickness of 8 cm. Nowadays, the technology of Self-Consolidating Concrete (SCC) grows rapidly (Kiousis & Whitcomb 2007, Sideris 2007, Georgiadis et al. 2010 among else). SCC may enable for efficient jackets even thinner than 8 cm, cast with poured concrete. Several researches focus on developing a workable and stable self-consolidating concrete suitable for casting it in place. However, other significant features affecting the safety of the designed member need further investigation. The force transfer between old and new concrete interfaces is of great significance (Tassios 1983, 1986, Vintzeleou & Tassios 1987). Especially, the interfaces resulting without special treatment of the existing concrete surface (no roughening or aggregate exposure through sandblasting) are crucial as they could be considered as lower limit cases of force transfer capacity.

The presented study deals with the mechanical behavior of reinforced concrete columns with dimensions 150x150x750 mm height, strengthened by a thin 40 mm steel reinforced jacket using cast-in place self-consolidating concrete. The columns varied by the common measures taken in practice to restore the monolithic behavior of the jacketed columns. No external surface treatment of the existing columns took place. The columns were subjected to axial compression cycles of increasing displacement. The mechanical behavior of the columns was assessed through their load versus axial strain curves.

2. TESTS

The tests included 7 columns of square section with dimensions 150 mm and 750 mm height. Five columns were externally confined by full reinforced concrete (rc) jacket while one reinforced concrete column and one plain concrete column were left unstrengthened to assess the behaviour of the existing column (core column) and the effect of slender longitudinal bars (figure 2.1a & b). Only the core columns were loaded and not the jackets (figure 2.1.c)

2.1. Material properties

The columns were constructed with ready – mixed concrete conforming to C12 category. The average 28-day concrete compressive strength of three standard cylinders (150 mm diameter and 300 mm height) was 14 MPa (old type concrete building).

All the specimens included smooth bars of 8 mm diameter and closed stirrups of 5.5 mm diameter both having a nominal yield stress of 220 MPa (also old type steel with low yield strength). The constructed jackets contained longitudinal ribbed reinforcements of 8 mm diameter with nominal yield stress of 500 MPa. The stirrups of the jacket were identical to the ones of the existing columns.

The jackets were constructed with cast-in place self-consolidating concrete targeting C30 category. The average 28-day concrete compressive strength of three standard cylinders was 41.8 MPa (conforming to C30 category).

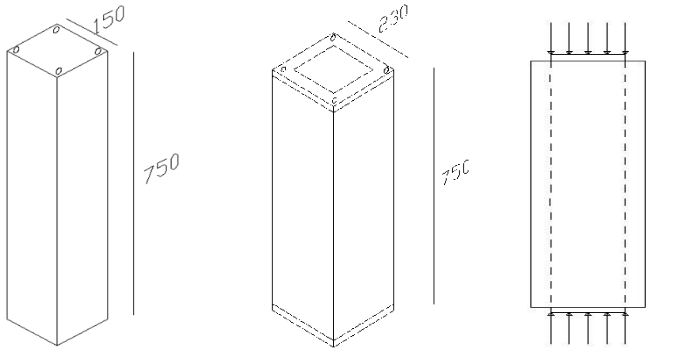
2.2. Specimens' characteristics and instrumentation

The 6 as-built rc columns (cores) contained 4 longitudinal smooth steel bars with a volumetric ratio of 0.9%. The spacing of 5.5 mm diameter transverse steel stirrups was 100 mm (closer at the ends to avoid undesirable failures out of the test region). The concrete cover was 10 mm in accordance with the previously selected geometrical parameters of a 1:2 scaled column.

At the second phase, the 5 out of 6 rc columns were jacketed by a thin 40 mm rc jacket using cast-in place self-consolidating concrete. The jackets had 4 longitudinal steel bars of 8 mm diameter with a volumetric ratio of 0.66%. The spacing of the 5.5 mm diameter transverse steel stirrups of the jacket was 50 mm.

The columns varied by the common measures taken in practice to restore the monolithic behaviour of the jacketed columns (figure 2.2a, table 2.1). The columns SRJ1 and SRJW1 included the casting of the concrete jacket without any prior treatment of the existing column surface. The column SRJWD1 had in addition dowels fixed on existing column, extended in the jacket, according to existing recommendations (figure 2.2b). The columns SRJWDH1, SRJWDH2 had dowels and the longitudinal reinforcements of existing column and jacket were welded together through steel bar connectors (hangers, figure 2.2c, 2.2d). The detailing of dowels and hangers is illustrated in figures 2.3a and 2.3b. All jackets except for the specimen SRJ1 had the overlapped edges of each stirrup welded. No specimen included as-built column special surface treatment.

The columns were subjected to repeated axial compression cycles under a displacement control mode of increasing magnitude. For the measurement of average axial and lateral strains, five linear variable displacement transducers (LVDTs) were used according to figure 2.4. Strain gauges were also used in column SRJWDH1 but the results are not discussed herein.

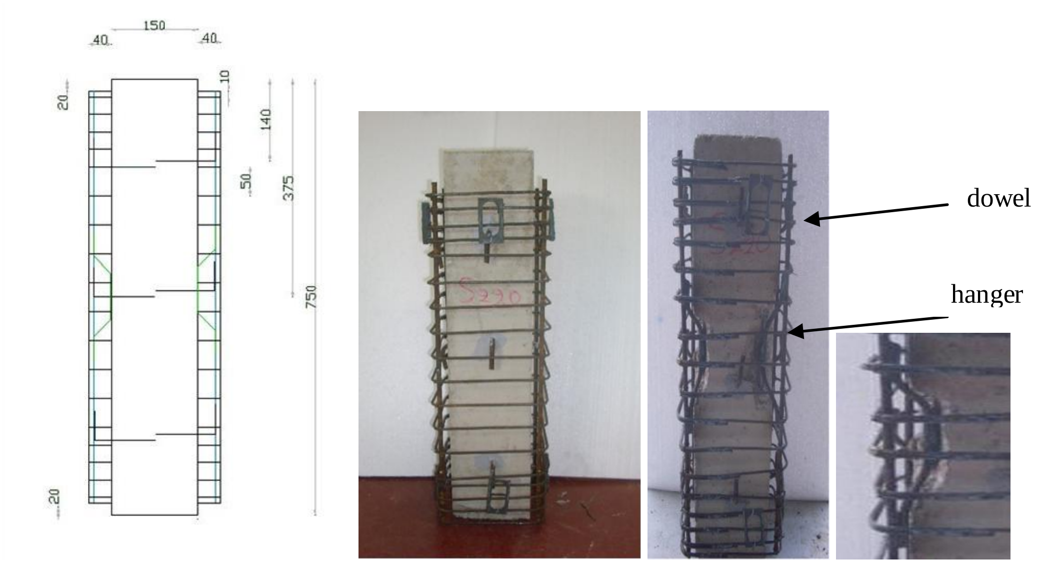


(a) (b) (c)

Figure 2.1. As-built columns (a), specimens with rc jackets (b) and core loading (c).

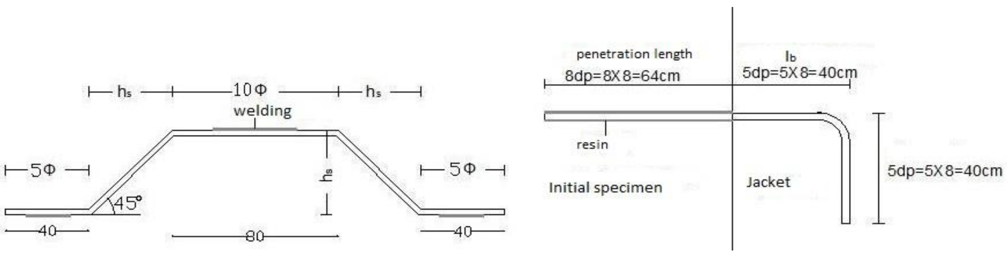
Table 2.1. Specimens' construction details

Specimen	Welded Stirrups	Dowels	Hangers
SRJ			
SRJW1	X		
SRJWD1	X	X	
SRJWDH1	X	X	X
SRJWDH2	X	X	X



(a) (b) (c) (d)

Figure 2.2. Details of jacket with dowels and hangers (a), dowels (SRJWD1) (b) dowels and hangers (SRJWDH1) (c), detail of hanger (d).



(a) (b)

Figure 2.3. Hangers (a) and dowels (b).

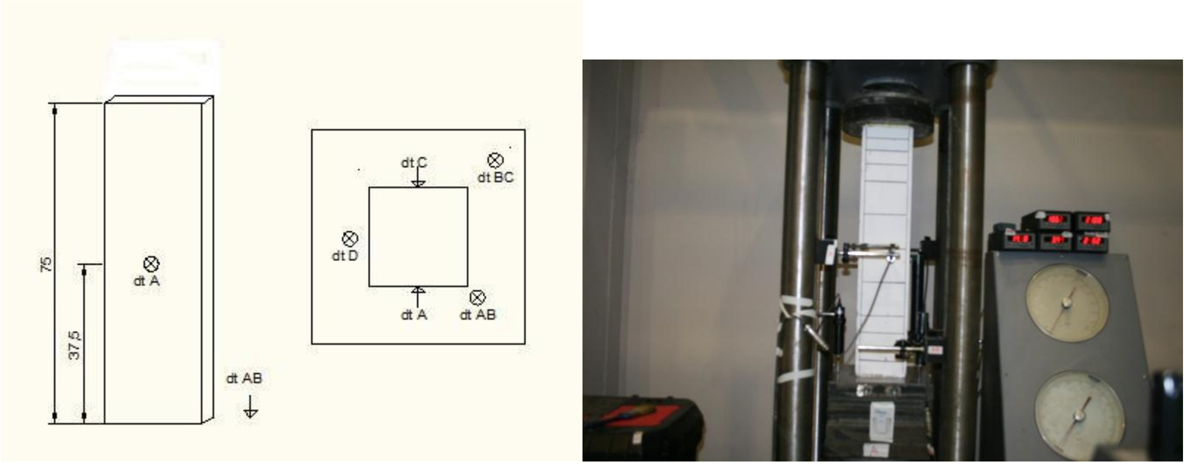


Figure 2.4. Instrumentation of jacketed columns with five LVDTs.

3. RESULTS

Figures 3.1-3.6 show the specimens at the post-elastic strain level that corresponds to 0.8fcc. The buckling effect at the as-built column SR1 is obvious. Column SRJ, with unwelded stirrups develops a major crack mainly on the upper part of the jacket along the axis of the column. The column with dowels has also a damaged region inside the jacket, around the dowels. Columns SRJWDH1 & 2 with dowels and hangers in bars present rather similar crack patterns to the specimens with dowels (Figures 3.5 and 3.6). The data for the column SRJW1 are available up to 0.022 strain because of a data acquisition malfunction. This specimen is pictured at 2.2% axial strain (Figure 3.2) with minor cracking of the reinforced concrete jacket at the middle of the side of the jacket.

The mechanical behavior of the columns was assessed through their load versus axial strain curves (Figures 3.7 and 3.8). The comparative σ-ε diagram that presents the envelope experimental curves, suggests that all jacketed columns subjected to pseudoseismic loading, have a remarkably enhanced strength and ductility because of the confinement by the reinforced SCC thin jacket. The maximum bearing stress recorded in column SRJWDH2 is 1.76 times that of the SR1 column while the maximum failure strain (at 0.8fcc) is 3.14% (see Table 3.1). The higher bearing axial stress is acquired in columns with hangers and dowels or with dowels only (from 23.61 MPa to 25.71 MPa, see Table 3.1). The columns with hangers and dowels develop their maximum stress earlier (corresponding strains of 0.91%-1.31%) than this with dowels only (1.69% strain) or without any interface treatment (1.22% for welded stirrups and 1.70% for SRJ). In the case of no interface treatment and with stirrup welding the strain of maximum stress was lower than in the specimens with no welded stirrups. The post-peak failure strains (at 0.8fcc) are similar for all the jacketed columns and vary between 3.0% and 3.14%.

The absorbed energy capacity is greatly enhanced in jacketed columns (more than 5 times with reference to unjacketed column). The higher absorbed energy is calculated in column SRJWDH1.

Figure 3.1. SR1 .

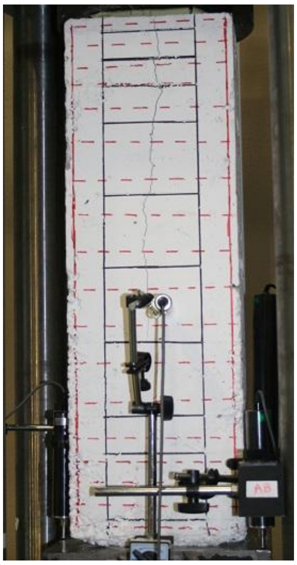


Figure 3.2. SRJW1*.

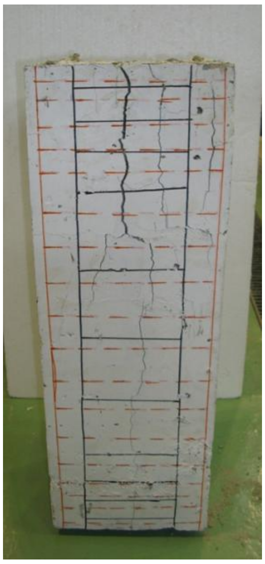


Figure 3.3. SRJ1 .

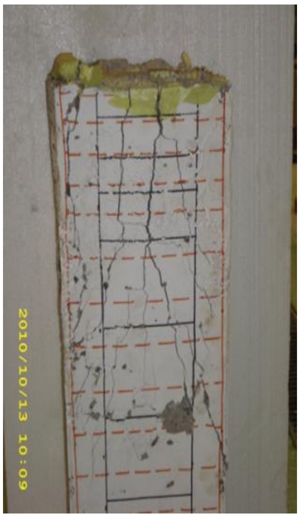


Figure3.4. SRJWD1.

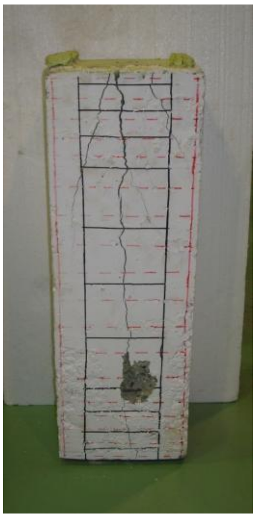


Figure 3.5. SRJWDH1.

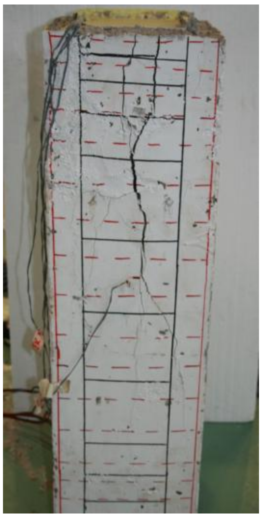


Figure 3.6. SRJWDH2

Table 3.1. Experimental results of tested columns

Specimen	Maximum bearing stress f_{cc} (Mpa)	Axial strain at maximum stress ε_{cc}	Failure stress fcu (MPa)	Failure strain ε_{cu}	Normalized absorbed energy (MJ/m^3)
S1 Plain concrete 15x15	13,67	0,0030	10.93	0,0040	0,0692
SR1 Reinforced concrete 15x15	14,60	0,0052	11.68	0,0098	0,1416
SRJ1	23,61	0,0170	18.88	0,0314	0,8762
SRJW1	23.15	0,0122	18.52	0,022	0,6330
SRJWD1	24.34	0,0169	19.47	0,0300	0,7928
SRJWDH1	25,71	0,0131	20.57	0,0311	1,1332
SRJWDH2	23,61	0,0091	18.89	0,0309	0,8636

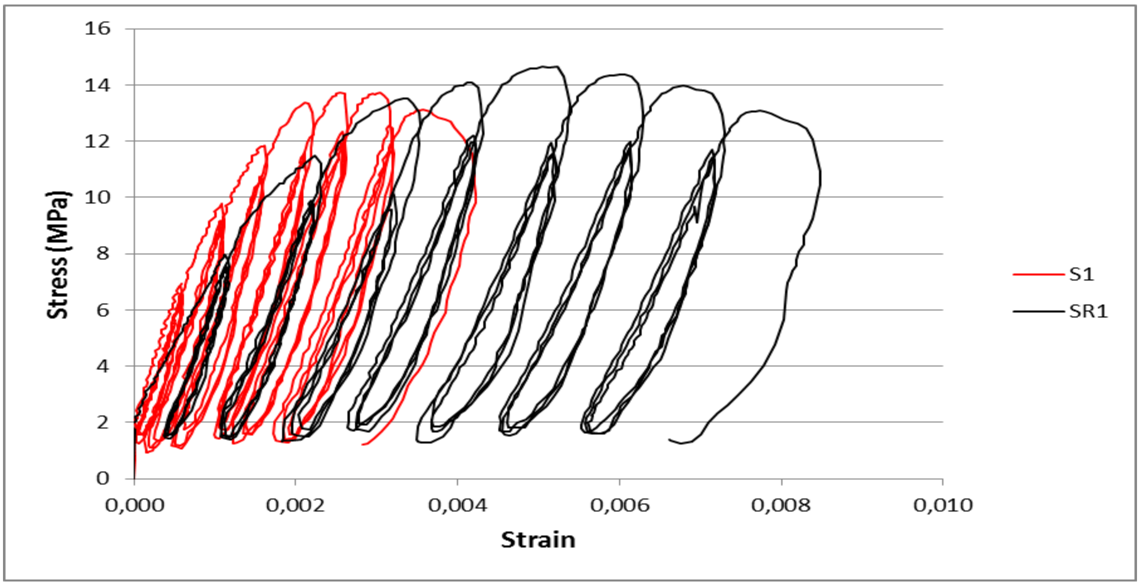


Figure 3.7. Stress – Strain curves of unjacketed plain concrete column S1 and rc column SR1

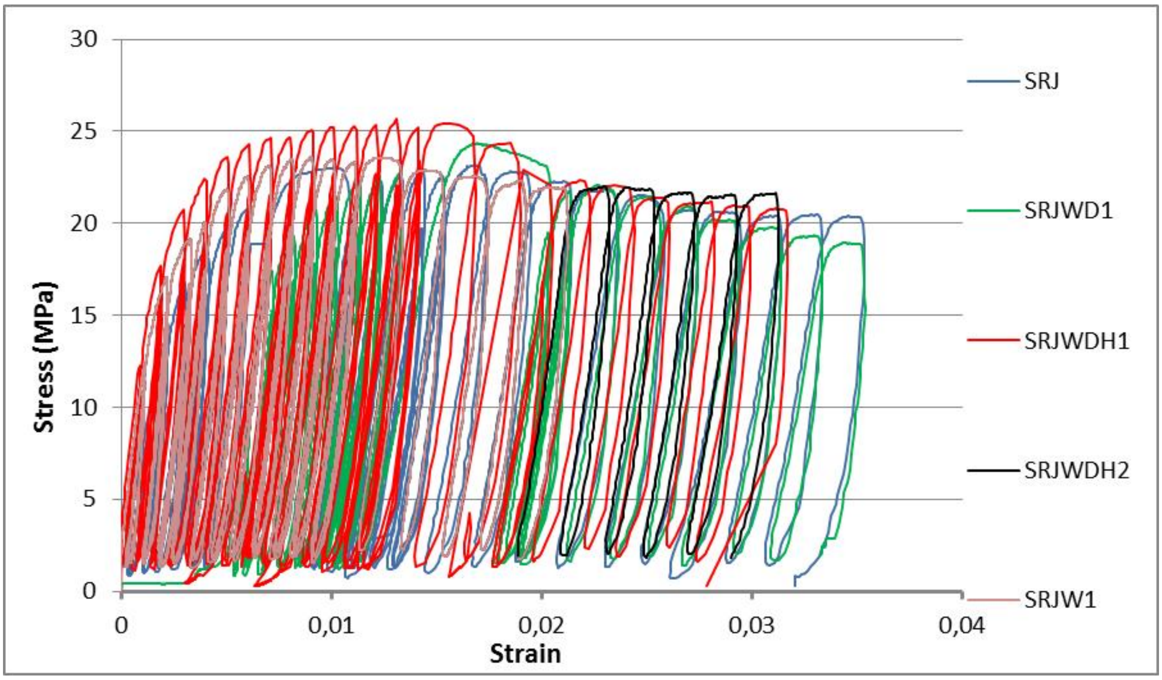


Figure 3.8. Stress – Strain curves of specimens with rc jackets

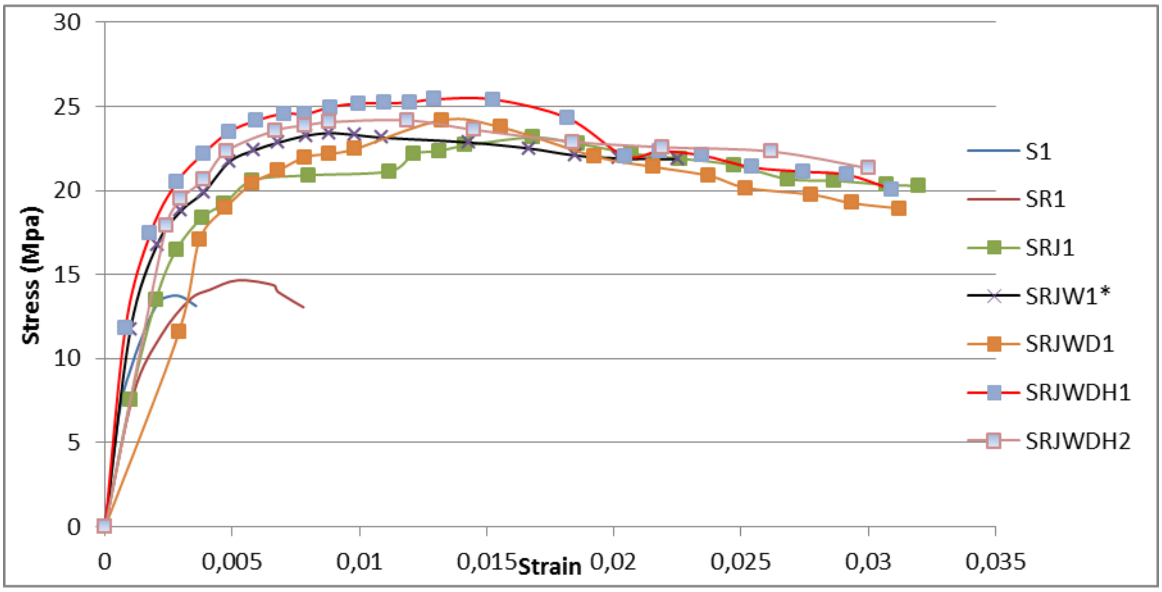


Figure 3.9. Envelope Stress – Strain curves of all columns

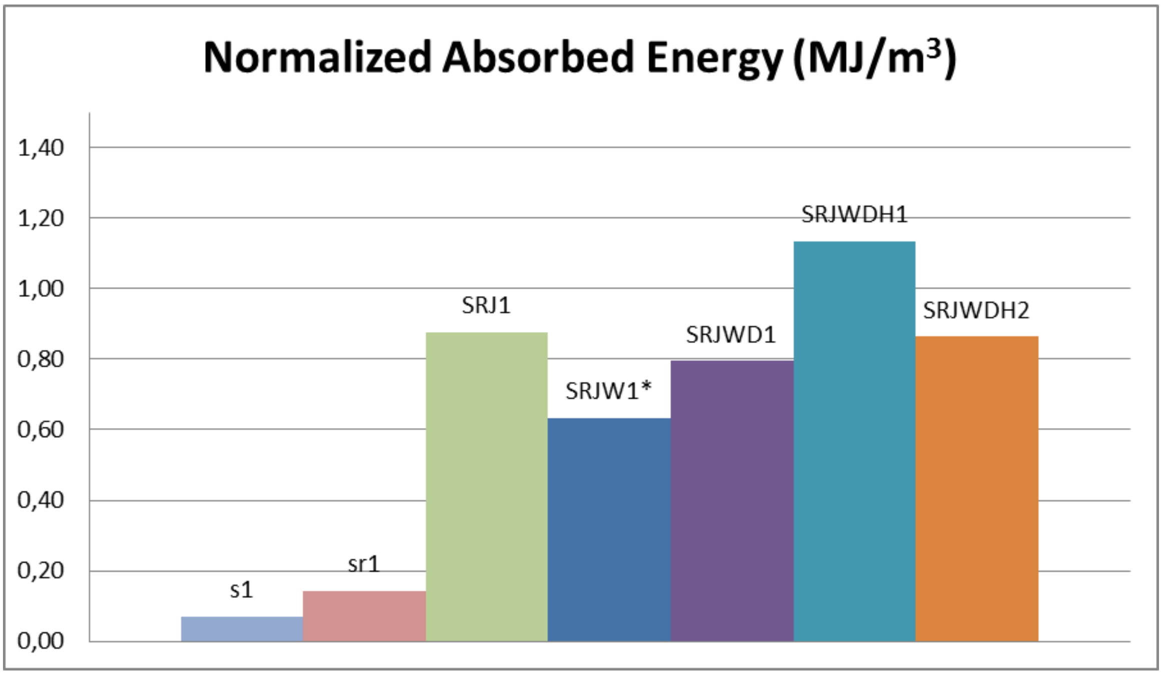


Figure 3.10. Normalized Absorbed Energy per Specimen (MJ/m^3)

5. CONCLUSIONS

The SCC thin reinforced concrete jacket is a viable retrofit technique using poured concrete. The reinforced SCC jacket provides a significant enhancement of the strength and ductility of the as-built column. The bearing load of the jacketed specimens at maximum and at failure is at least 50% higher than the as-built columns. The axial strain at 0.8fcc is about 3%. The absorbed energy in rc jacketed columns is more than 5 times higher than the corresponding of as-built column. The absence of special treatment of the outer surface of the core column or the welding of stirrups (or not) does not seem to affect the general stress-strain behavior of the confined columns through rc jackets. The presence of dowels or bars' hangers also provides similar confining effects in terms of maximum stress and failure strain. However the columns with dowels and hangers develop their maximum stress earlier.

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