UDK 666.97:620.181
Original scientific article/Izvirni znanstveni članek

ISSN 1580-2949
MTAEC9, 45(6)571(2011)

EVALUATION OF THE STRENGTH VARIATION OF NORMAL AND LIGHTWEIGHT SELF-COMPACTING CONCRETE IN FULL SCALE WALLS

OCENA VARIACIJE TRDNOSTI NORMALNEGA IN LAHKEGA VIBRIRANEGA BETONA V POLNIH STENAH

M. M. Ranjbar[1], M. Hosseinali Beygi[2], I. M. Nikbin[3] , M. Rezvani[4], A. Barari[5]

[1]Department of Civil Engineering, Guilan University, Rasht, Iran
[2]Department of Civil Engineering, Babol University of Technology, Babol, Iran
[3]Department of Civil Engineering Islamic Azad University, Rasht Branch, Rasht
[4]Institute of Material Science, University of Duisburg-Essen, Universitätstrasse 15, 45141 Essen, Germany
[5]Department of Civil Engineering, Aalborg University, Sohngardsholmsvej 57, 9000 Aalborg, Aalborg, Denmark
ab@civil.aau.dk, amin78404@yahoo.com

Prejem rokopisa – received: 2011-03-26; sprejem za objavo – accepted for publication: 2011-06-10

The strength of cast concrete along the height and length of large structural members might vary due to inadequate compaction, segregation, bleeding, head pressure, and material type. The distribution of strength within a series of full scale reinforced concrete walls was examined using non-destructive testing. Self-compacting concrete (SCC) and lightweight self-compacting concrete (LWSCC) with different admixtures were tested and compared with normal concrete (NC). The results were also compared with results for standard cubic samples. The results demonstrate the effect of concrete type on the in situ strength variation and the relationship to the strength of standard cube samples. Investigation of the strength variation along the height of the wall showed that SCC mixes had better strength uniformity and that the NC mix had the greatest strength variation. There were no significant strength differences between mixtures along the length of the walls. Furthermore, different admixture replacements did not have a meaningful effect on the strength distribution.

Keywords: strength variation, self-compacting concrete, lightweight aggregate, ultrasonic pulse velocities, compressive strength, structural walls.

Trdnost litega betona po višini in dolžini večjih gradbenih elementov lahko variira zaradi neprimernega vibriranja, segregacije, iztekanja (solzenja), pritiska glave in vrste materiala. Porazdelitev trdnosti v seriji železobetonskih cementnih sten je bila preiskana z uporabo neporušnih preizkusov. Vibrirani beton (SCC) in lahek vibrirani beton (LWSCC) iz različnih zmesi sta bila primerjana z normalnim betonom (NC). Rezultati so bili primerjani tudi z rezultati za standardne kockaste vzorce. Rezultati dokazujejo učinek vrste betona na *in situ* variacijo trdnosti in odvisnost od trdnosti standardnih kockastih vzorcev. Raziskava trdnosti vzdolž višine stene je pokazala, da različne zmesi ne vplivajo pomembno na porazdelitev trdnosti.

Ključne besede: variacija trdnosti, vibrirani beton, lahek agregat, hitrost ultrazvočnega impulza, tlačna trdnost, zidovi konstrukcij

1 INTRODUCTION

In the past two decades, self-compacting concrete (SCC) has been developed to build concrete structures. Practical applications of SCC vary widely and have been accompanied by numerous research studies. SCC is a flowable concrete that fills spaces, especially in sections with highly congested reinforced members and restricted shapes.[1] SCC has less stringent working and safety requirements because of its negligible vibration factor. The weight of SCC is the main cause of its compaction. Its significant advantages, such as favorable mechanical properties and durability, have made SCC a high-performance concrete. Most of the probable bleeding and segregation can be reduced with viscosity-modifying agents in SCC mixes. Consequently, due to the elimination of any voids, the maximum density, material strength and concrete-steel rebar bonding are improved. Furthermore, SCC provides easier transition and pumping. Hence, the casting process is faster for huge structural members.[1,2,3]

Structural lightweight concrete has a lower density in place compared to normal weight concrete. The concrete mixture is made with a lightweight aggregate. The main application of structural lightweight concrete is to decrease the dead load of concrete structures such as high-rise buildings and long-span bridges, which then allows the structural designer to reduce the size of piers, footings, walls and other load-bearing elements.[4] Furthermore, it can decrease the applied dynamic loads, such as earthquake forces, which are directly related to the dead load of a structure. It has been shown that a decrease in the dimensions of structural members compensates for the higher cost of lightweight concrete.[5]

Variations in the strength of concrete in a structure and control samples of a similar age are fundamentally due to differences in curing conditions and compaction. These factors also affect the strength variations within the depth of the members. Variations in a concrete supply are due to the variety of batching, materials, placing and handling methods, which are often restricted by the quality control of a production, such as the compliance testing of control samples. These factors are clearly not related to the member type involved but lead to random in situ variations. Previous research has shown positional differences along the height of concrete members cast in a deep form, and the lowest strength occurred at higher positions due to the concrete pressure head, aggregate settlement, bleeding and pores, which cause inadequate compaction. Another reason for this type of variation is the upward movement of water through concrete while the material is still plastic and the fact that upper layers protect the lower layers of concrete from rapid drying.[6–9]

Considering the nature of self-compacting concretes, which have a high consistency and flow ability, the homogeneity of these concretes in comparison to normal concrete that is compacted traditionally has been evaluated. Previous studies performed by Zou and Khayat on reinforced concrete beams, columns at large scales and un-reinforced walls relative to small scale walls made of self-compacting and normal concretes showed that the members made of self-compacting concrete had higher homogeneity but some discrepancies within and between them.[10,11]

On the other hand, in many situations, the standard cube sample strength may not indicate the actual strength of the concrete members. Therefore, the concrete strength of full scale reinforced concrete walls in service sites was evaluated. The ultrasonic pulse velocity test was used to investigate the strength variation and uniformity of in situ concrete strength.

2 EXPERIMENTAL PROGRAM

To study the homogeneity of normal weight self-compacting concretes and lightweight self-compacting concretes, five (2.0 × 2.0 × 0.2) m reinforced concrete walls were cast. The strength distribution in the structural walls and their variations with the normal weight concrete (NC) were also studied. The walls contained reinforcing steel 12 mm in diameter and 25 cm in length. Steel reinforcement details for the walls are given in **Figure 1**. This reinforcement configuration was selected to assess the effect of steel bars on the compaction of self-compacting concretes.

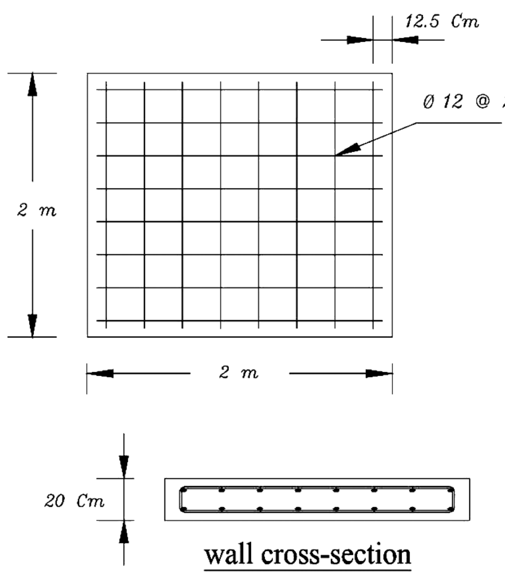


Figure 1: Details of reinforcement for the walls
Slika 1: Detajli utrditve stene

Concrete mix with a specified cube strength of 28 MPa was considered, and Type I Portland cement conforming to BS12 was used throughout the tests. The lightweight aggregate used in this research was Leca with a 24 h water absorption of 14 %. Other research has shown that domestic Leca has lower levels of resistance compared to its foreign counterparts.[11] Hence, Leca was used as a fine aggregate and substitute for part of the natural sand. The natural river sand, 1.46 % water absorption, was the other part of the fine aggregate. It was washed before use in the mixture procedures. The normal coarse aggregate was crushed stone with a maximum size of 20 mm and 0.8 % water absorption, except for the lightweight concretes, where the maximum size was 10 mm with 0.5 % water absorption. Limestone powder was used to maintain the viscosity of the fresh mix and hence to reduce the segregation phenomena. The chemical characteristics of the cement and mineral admixture are presented in **Table 1**. Superplasticizer Viscocrete 1 was introduced into the mixes. The properties of the concrete mix used in this study and the properties of the fresh concrete are shown in **Tables 2 and 3**, respectively. SSCC and SLWSCC (Light weight self-compacting concrete containing silica fume) produced mixtures containing 7.0% silica fume by weight of cement content. NSCC and NLWSCC (Light weight self-compacting concrete containing nano-sized SiO_2) had mixtures containing nano-sized SiO_2 with a particle size of 15 nm in the amount of 3.0 % by weight of cement content.

Full scale walls were cast in steel molds. To simulate the site construction, workshop executives and technical

Table 1: Chemical properties of cement and mineral admixtures
Tabela 1: Kemična sestava cementnih in mineralnih zmesi

	mass fractions, *w*/%			
	Cement	Silica fume	Limestone filler	Nano SiO_2
SiO_2	22.02	96.4	–	99.9
Al_2O_3	4.40	1.32	–	–
Fe_2O_3	3.20	0.87	–	–
CaO	64.9	0.49	–	–
MgO	1.42	0.97	–	–
SO_3	1.67	0.10	–	–
Na_2O	0.27	0.31	–	–
LOI	1.30	–	–	0.1
P_2O	–	0.16	–	–
$MgCO_3$	–	–	1.10	–
$CaCO_3$	–	–	98.1	–

Table 2: Mixture proportions
Tabela 2: Sestava zmesi

Coarse Agg	Fine Agg. (kg/m^3)	Leca 0–3 mm (kg/m^3)	Limestone powder (kg/m^3)	Water (kg/m^3)	Superplasticizer (kg/m^3)	Nano SiO_2 (kg/m^3)	Silica fume (kg/m^3)	Cement (kg/m^3)	Mixture Type	
									10–20 mm (kg/m^3)	5–10 mm (kg/m^3)
648	349	815	–	–	200	–	–	–	320	NC
384	469	873	–	270	181	8	–	22.4	300	SSCC
384	469	873	–	270	166	8.5	9.6	–	310	NSCC
–	250	382	245	290	198	9.8	–	30.8	440	SLW-SCC
–	250	382	245	290	205	10.2	14.1	–	456	NLW-SCC

Table 3: Fresh properties
Tabela 3: Lastnosti svežih vzorcev

Mix Type	Slump flow		V/s Funnel	L-Box (h_2 / h_1)	Unit weight (kg/m^3)
	T_{50}/s	D/cm Final			
NC	–	–	–	–	2395
SSCC	2.2	68	7.2	0.93	2373
NSCC	2.5	65	7.8	0.94	2362
SLW-SCC	3.8	69	8.1	0.91	1840
NLW-SCC	4.2	63	7.9	0.90	1831

staff were involved. The concrete was supplied in four 0.3 m^3 batches. During the concreting of the reinforced concrete walls, the different concretes were poured directly from the top of the walls without any external vibration into the framework except for the wall made of normal concrete, which was compacted with a common vibrator. Specimens were cured under wet textiles and polythene sheets for 7 d. Five 100 mm cubes were also cast from each of the four batches. Half of the cubic specimens were subjected to curing conditions similar to those of the walls, and other half were treated with the standard curing regime.

3 TEST PROCEDURES

3.1 Ultrasonic Pulse Velocity (UPV) Test

Non-destructive tests of concrete are preferred because measurements can be obtained without destructive forces. The most generally used method is the ultrasonic pulse velocity method. The test procedure is based on the fact that the velocity of an ultrasonic pulse wave in solid bodies depends on the modulus of elasticity, Poisson's ratio and the density of the material. When the uniformity, density and homogeneity of the concrete are good, ultrasonic pulse waves of higher velocity can be observed. Generally, acoustic transducers are used to generate ultrasonic pulses.[12] When the pulse wave passes through concrete, it undergoes various reflections at the boundaries of materials with different properties within the concrete body. The velocity of the pulse waves is often independent of the geometrical shapes of the materials through which they pass. The pulse velocity test is a common method to assess structural concrete. The actual pulse velocity wave obtained depends mainly on the materials and mixture of concrete.

After traveling a known path length (L) in the concrete, the pulse is converted into an electrical signal by a second electro-acoustical transducer, and an electronic timing circuit enables the transfer time (T) of the pulse to be recorded. The pulse wave velocity (V) is obtained by

$$V = \frac{L}{t} \tag{1}$$

where V/(km/s) pulse wave velocity, /cm length of path, and /μs transfer time

The longitudinal ultrasonic pulse waves that leave the transmitter travel in the direction normal to the transducer surface according to BS 1881 [13]. To make a reasonably accurate and relevant assessment of the uniformity of the concrete strength in existing walls in this study, the ultrasonic pulse velocity test was used as a non-destructive test method. Ultrasonic pulse velocity (UPV) tests on the walls at 21 d were performed using Pundit equipment [14]. The pulse velocity measurements were taken directly through the thickness of the walls at the grid locations indicated in **Figure 2**. The UPV test locations included 21 points, which were located at the top, middle and bottom levels at heights of (175, 100 and 25) cm, respectively, above the bottom surface of the walls. These locations were chosen to test different levels within the walls while satisfying the minimum edge distance and spacing requirements and avoiding reinforcing steel.

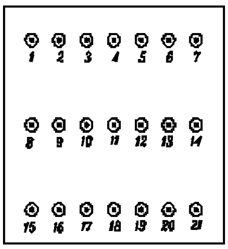


Figure 2: Test positions on the walls
Slika 2: Mesta preizkusov v stenah

Table 4: Hardened properties
Tabela 4: Lastnosti strjenih vzorcev

Mix Type	Compressive Strength (MPa)				Ultrasonic Pulse Velocity (km/s)			
	3 days	7 days	14 days	28 days	3 days	7 days	14 days	28 days
NC	14.2	19.4	23.3	29.0	3.61	3.78	3.89	3.98
SSCC	26.9	29.1	29.8	33.0	3.96	4.08	4.11	4.27
NSCC	30.3	32.3	33.8	35.5	4.26	4.27	4.31	4.36
SLWSCC	22.5	23.4	24.0	25.3	4.04	4.08	4.09	4.14
NLWSCC	24.0	26.8	27.2	27.0	4.07	4.18	4.21	4.22

4 RESULTS AND DISCUSSION

4.1 Compressive strength

To obtain the compressive strength and UPV, the walls were tested at the ages of (3, 7, 14 and 28) d. The compressive strengths of five 100 mm cube specimens were tested at the ages of (3, 7, 14 and 28) d. All results were the average of five 100 mm cubes. The UPV measurements were repeated three times for each cube specimen. The values found for the compressive strength and UPV tests of the mixtures at different ages are tabulated in **Table 4**.

4.2 The relationship between the ultrasonic pulse velocity and the compressive strength

From the data listed in **Table 4**, which shows the averages of the compressive strength and UPV test results, a regression analysis for the pulse velocity versus compressive strength of the cube samples for each mixture was performed. The correlations were established using an exponential curve model. The pulse velocity functions and the correlation coefficient (R^2) are presented in **Table 5**. The high correlation coefficient of the numerical formula indicates the suitability of the functions.

Table 5: Relationships between compressive strength and in-place test results
Tabela 5: Odvisnost med tlačno trdnostjo in rezultati *in situ* preizkusov

Mixture Type	Regression equations	
	Pulse velocity function	Correlation coefficient (R^2)
NC	$f'c = 0.0204\ e^{1.8142V}$	0.9217
SSCC	$f'c = 1.906\ e^{0.6679V}$	0.9412
NSCC	$f'c = 0.0801\ e^{1.3998V}$	0.8914
SLWSCC	$f'c = 0.1857\ e^{1.1872V}$	0.9873
NSLWSCC	$f'c = 0.7731\ e^{0.845V}$	0.9646

4.3 Distribution of the concrete strength within concrete walls

The results of ultrasonic pulse velocity measurements at different test points at the age of 28 d are presented in **Figure 3**. The concrete compressive strength of the reinforced concrete walls was determined by measuring the ultrasonic pulse velocity along the wall thickness and converting it to the cube compressive strength using the relevant function. The average of the ultrasonic pulse velocity measurements and the estimated compressive strength using the pulse velocity functions are summarized in **Table 6**.

The strength distribution of the concrete at the levels of (25, 100 and 175) cm from the bottom of the walls was studied. For all mixes, the strength variation in the walls showed that the bottom regions of the walls were stronger than the top regions. Some trends were also previously observed in structural members of normal and lightweight concrete and self-compacting concrete.[5–11] The phenomenon of strength reduction along the height of the members was probably due to several factors. Toosi et al. studied the strength variation of normal concrete and showed that local segregation and bleeding occur under aggregates, which leads to microcracks and voids beneath the aggregate surface. Therefore, the paste-aggregate bond is weakened. They also showed bond improvement because of the increase of the pressure head in the lower layers.[8] In the case of lightweight concrete, a nonuniform density distribution also occurs because of the porosity and floating of the lightweight aggregates in fresh concrete. Consequently, lightweight aggregates tend to move to the upper levels of concrete

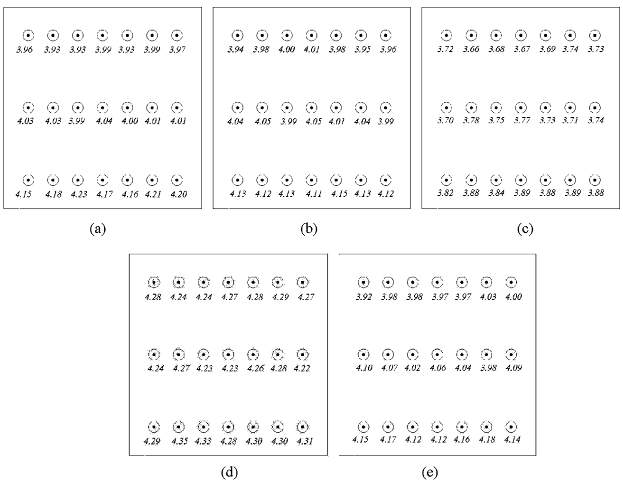


Figure 3: Ultrasonic pulse velocity measurements in different test points of the reinforced concrete walls: (a) SSCC, (b) SLWSCC, (c) NC, (d) NSCC and (e) NLWSCC
Slika 3: Meritve hitrost ultrazvoka v različnih točkah ojačenih betonskih sten: (a) SSCC, (b) SLWSCC, (c) NC, (d) NSCC, in (e) NLWSCC

Table 6: Estimated in situ strengths and test results (28 days)
Tabela 6: Ocenjene *in situ* trdnosti in rezultati preizkusov (28 d)

Level of walls	NC		SSCC		NSCC		SLWSCC		NLWSCC	
	f'_c (MPa)	UPV measurements (km/s)	f'_c (MPa)	UPV measurements (km/s)	f'_c (MPa)	UPV measurements (km/s)	f'_c (MPa)	UPV measurements (km/s)	f'_c (MPa)	UPV measurements (km/s)
Top	16.7	3.70	26.8	3.95	31.5	4.27	20.7	3.97	22.3	3.98
Middle	18.3	3.74	27.9	4.01	30.7	4.25	22.0	4.02	23.7	4.05
Bottom	23.2	3.87	31.2	4.19	33.4	4.31	24.9	4.12	25.8	4.15
Average	19.4	3.77	28.6	4.05	31.8	4.27	22.5	4.03	23.9	4.06

Note: f'_c = Cube compressive strength.

members. This phenomenon is more intense if coarse lightweight aggregate is used.[15] Previous research has shown that the tendency of segregation decreases with increasing the mineral admixtures contents.[16] The relative concrete strength variation at different levels with respect to the concrete strength at the bottom level of the mixtures is shown in **Figure 4**.

Figure 4 shows that the strength of middle and upper levels in comparison to the lower level decreased by 8 % and 14 % for NLWSCC, 10 % and 8 % for NSCC, 11.4 % and 16.5 % for SLWSCC, 11 % and 14.5 % for SSCC and 21 % and 28 % for normal concrete. The results indicated a similar trend for the normal weight self-compacting concrete mixes (SSCC and NSCC) and lightweight self-compacting concrete (SLWSCC and NLWSCC), and there was a significant discrepancy between the self-compacted mixtures and the normal concrete mix. It is possible that the results could be different due to the use of more Leca, especially coarse aggregates. As predicted, because of the use of mineral admixtures and a fine lightweight aggregate in this study, a lower tendency of segregation was observed in the SLWSCC and NLWSCC mixtures. In other words, lightweight self-compacting concrete had greater homogeneity than the normal concrete, but compared with normal self-compacting concrete, it showed less homogeneity.

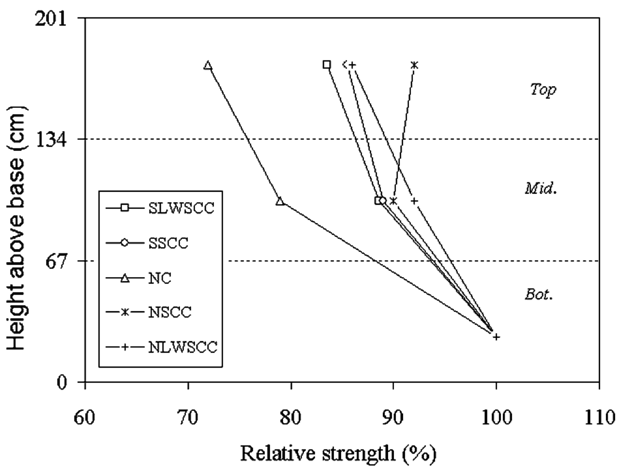


Figure 4: In situ strength variations across the height of the walls
Slika 4: Variacije *in situ* trdnosti po višini sten

Because self-compacted mixtures contain a lower coarse aggregate volume of smaller sizes compared to NC, the size and quantity of microcracks are much lower in self-compacted mixtures, which leads to paste-aggregate bond improvement. As mentioned above, the effects of head pressure and local segregation on the strength variation are much lower in self-compacted mixes than in NC. Some previous reports indicated considerable statistical discrepancies in the homogeneity of properties.[10,11] However, in this study significant differences in strength variation between self-compacted concrete and NC were observed. Khayat showed a similar trend of changes in the

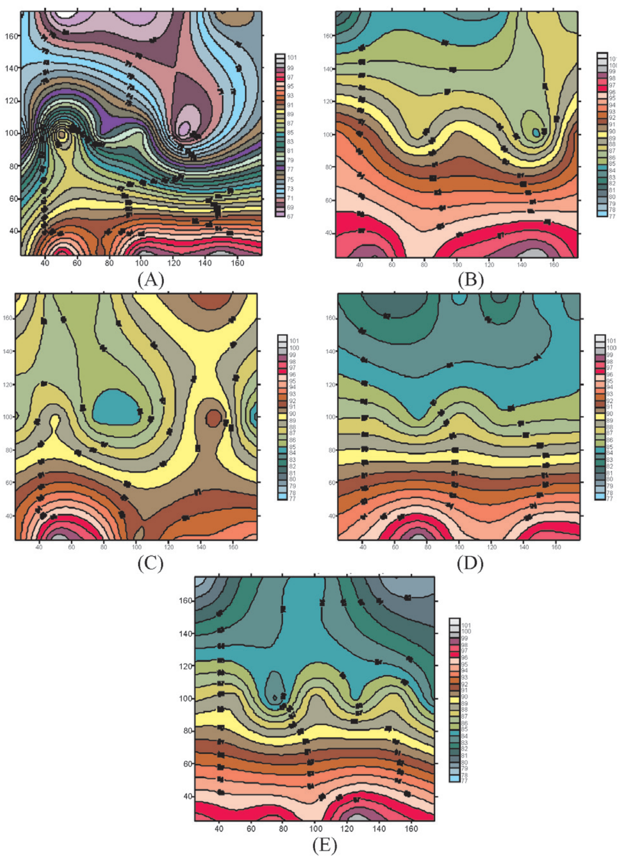


Figure 5: Stress contour plots based on 28-d UPV measurements: (a) NC, (b) NLWSCC, (c) NSCC, (d) SSCC, and (e) SLWSCC
Slika 5: Porazdelitev napetosti na podlagi 28-dnevnih meritev UPV: (a) NC, (b) NLWSCC, (c) NSCC, (d) SSCC in (e) SLWSCC

Table 7: Comparison of cube strengths and estimated in situ strengths
Tabela 7: Primerjava trdnosti kock in ocenjenih *in situ* trdnosti

Mixture type	Level	f: Estimated in situ cube strength (MPa)	f'_c: 28 day standard cube strength in wet-cured condition (MPa)	$\frac{f}{f'_c}$
NC	Top	16.7	27.0	0.62
	Mid.	18.3		0.64
	Bot.	23.2		0.86
SSCC	Top	26.8	32.8	0.82
	Mid.	27.9		0.85
	Bot.	31.2		0.95
NSCC	Top	31.5	32.7	0.96
	Mid.	30.7		0.94
	Bot.	33.4		1.02
SLWSCC	Top	20.7	25.5	0.81
	Mid.	22		0.86
	Bot.	24.9		0.97
NLWSCC	Top	22.3	28.0	0.97
	Mid.	23.7		0.84
	Bot.	25.8		0.92

concrete strength of normal self-compacting and normal concrete walls.[11] However, the walls that Khayat considered were not full scale or reinforced. Hence, the effects of the reinforcement configurations on compaction were not considered, and more studies are necessary. The in situ strength variability is shown in the contour plot of **Figure 5**. This contour plot provides further comparison of the strength variation within the walls both across their height and their length. Random variation along the member length was noted. **Figure 6** shows the strength changes with specific trends along the wall height. However, this trend varied for different mixtures. The NC wall exhibited more intensive discrepancies because of the effect of the internal vibration on the compaction of the concrete.

In **Table 7**, the wet-cured standard cubic compressive strengths are compared with equal cubic strengths at different levels of the walls. Figure 6 shows that the in situ strength varied from 81 % to 102 % of the wet-cured standard 28 d strength for all four self-compacted concrete walls. However, this difference was about 62 % to 86 % for the normal concrete wall. The main reason for the differences between the in situ and standard 28 d strengths is the low sensitivity of self-compacted mixtures to curing conditions. This observation was previously reported by Pera et al.[17] On the other hand, the high discrepancy between the lightweight self-compacting concretes and NC might be because the high initial moisture content of the lightweight aggregates led to typical internal curing. Thus, low sensitivity to the curing regime can be expected for lightweight self-compacting concretes.

A previous study showed 75 % to 90 % differences between the standard cube and in situ 28 d strengths for the SCC mixture.[11]

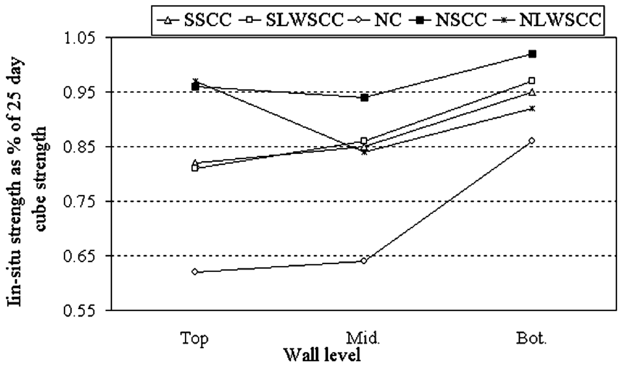
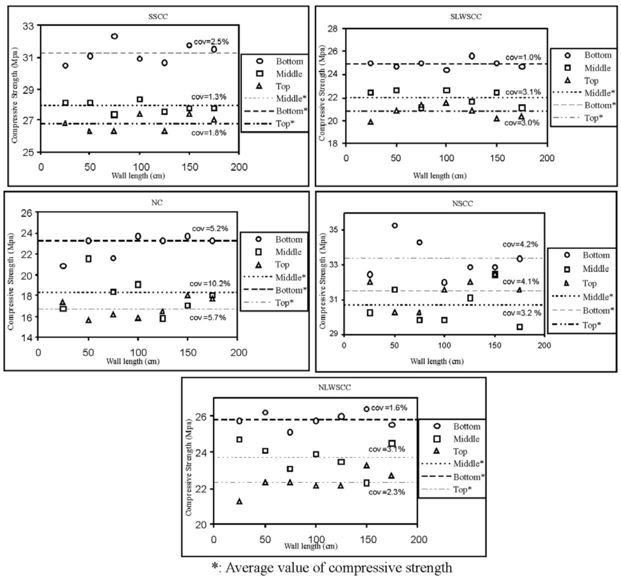


Figure 6: In situ compressive strength in walls in relation to standard 28 d strength
Slika 6: *In situ* tlačna trdnost v stenah v odvisnosti od standardne 28-dnevne trdnosti



*: Average value of compressive strength
Figure 7: Strength variations along the length of the walls with respect to the average value of each level
Slika 7: Variacije trdnosti po dolžini sten v razmerju s povprečno vrednostjo na vsakem nivoju

4.4 Distribution of concrete strength along the walls

Figure 7 indicates the coefficient of variation (COV) of strength for different heights along the experimental walls. The COV of strength measurements ranged from 1 % to 4.1 % for self-compacted mixes and were limited to 10.2 % for the NC mix. Therefore, the self-compacted mixtures had better uniformity along the length of the walls.

5 CONCLUSIONS

The following conclusions were drawn from the results presented in this paper concerning the variation of factors such as strength level, type of lightweight aggregate and admixture content.

1. Strength variations across the height of the reinforced concrete walls followed the general pattern of a reasonably uniform distribution from top to bottom, with the top region having a lower strength than the bottom region. However, the magnitude of this variation varied according to the concrete type.
2. The low in situ strength variations of all self-compacted mixtures showed greater strength uniformity than that of the NC mixture along the height of the walls.
3. Due to the low sensitivity of self-compacted mixes to curing conditions, smaller differences were observed in the self-compacted mixes than the normal concrete mix.
4. The COV of the strength measurements showed better uniformity for all normal self-compacting and lightweight self-compacting mixtures.
5. By replacing the silica fume with nano-sized SiO_2 as the admixture, no considerable changes were observed in strength variation trends.

6 REFERENCES

[1] Skarendahl, A., Petersson, O. Self compacting concrete: state-of-the-art report of RILEM TC 174-SCC, Report 23, RILEM Publishers, Cachan, France, **2000**

[2] Koyata, H., Comman, C. R. 2005. Workability measurement and developing robust SCC mixture designs. In proceeding if Second north American conference on the design and use of self consolidating concrete (SCC) and the fourth International RILEM Symposium on self compacting concrete. Addison, IL, USA: Hanley Wood Publishers, (**2005**), 799–805

[3] N'ielsson, I., Wallevik, O.H. In: Wallevik O, Nielsson I., **2003**. Rheologycal evaluation of some empirical test methods – preliminary results proceedings of the 3rd international RILEM symposium Reykjavik, Iceland. RILEM Publishers PRO, 33 (**2003**), 59–68

[4] Videla C., Lopez, M. Effect of lightweight aggregate intrinsic strength on lightweight concrete compressive strength and modulus of elasticity. Mater de construction, 52 (**2002**), 23–27

[5] Madandoust, R. Strength assessment of lightweight concrete. PhD thesis, The University of Liverpool; **1990**

[6] Bungey J. H., Madandoust R. Strength variation in lightweight concrete beams. Cem Concr Res., 34 (**2004**),1259–63

[7] Toosi, M., Houde, J. Evaluation of strength variation due to height of concrete members. Cem. Concr. Res., 11 (**1981**), 519–529

[8] Toosi, M. Variation of concrete strength due to pressure exerted on fresh concrete. Cem. Concr. Res., 10 (**1980**), 845–852

[9] Kumar, R., Bhattacharjee, B. Porosity, pore size distribution and in situ strength of concrete. Cem. Concr. Res., 33 (**2002**), 155–164

[10] Zho, W., Gibbs, J. C., Bartos, J. M., Uniformity of in situ properties of self compacting concrete in full- scale structural element, Cem. Concr. Compos., 23 (**2001**), 57–64

[11] Khayat, K. H, Manai, K., Trudel, A. In situ mechanical properties of walls elements cast using self consolidating concrete, ACI Mater J., 941 (**1997**), 491–500

[12] Malhotra, V. M., Carino, N. J. CRC handbook on non-destructive testing of concrete. CRC Press, **1997**

[13] Bungey, J. The testing of concrete in structures. London, Uk: Surrey university Press, **1989**

[14] PUNDIT Ultrasonic concrete tester. C. N. S. Electronics LTD, 61–63 Holms road, London, NW5, England

[15] Mindess, S., Young, J.F, Darwin, D. Concrete 2^{nd} Prentice Hall, **2003**

[16] Demirboğa, R., Örüng, I, Gül, R. Effect of expanded perlite aggregate and mineral admixtures on compressive strength of low density concrete. Cem. Concr. Res., 31 (**2001**), 1627–32

[17] Pera, J., Husson, S., Guilhot, B. Influence of finely ground limestone on cement hydration. Cem. Concr. Res. 21 (**1999**), 99–105