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Assessment of the Changes in Compressive Strength of Deep Beam Elements Using High Performance Self-Consolidating Concrete from a Single Casting Point

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Abstract. This experimental work investigates into the effect of a change in the compressive strength of concrete along the length and height of monolithic deep beams made of high performance self-compacting concrete (HPSCC). In the tests, three different HPSCC mixes were used in which the amount of silica fume differed (0, 5 and 10% by mass of cement). The binder content (550 kg/m^3) and the water-binder ratio (0.32) were the same. Experimental deep beams, measuring 1.50 m in length, 0.15 m in width and 0.45 m in height, were cast. A variant of casting was explored in which concrete is cast from the top of a mould from a single casting point at one edge of an element. All the HPSCC mixtures exhibited small variations in the compressive strength in relation to the length and height of the experimental deep beams. In general, those variations were limited to 8% and 16%, respectively. Casting HPSCC from a single casting point at one edge of an element may be used in practice as an alternative way of laying self-compacting concrete.

1. Introduction

Concrete is the most commonly used building material. The long history of its development, dating back to the time before the Common Era, is a series of changes in its content in order to improve the physical properties and ensure better durability. A continuous development of concrete technology over the last decades has led to the production of new generation concretes having qualitatively better characteristics not only in terms of strength and durability, but also rheology [1, 2]. Among new generation concretes, there is self-compacting high-performance concrete (HPSCC), which was designed based on the concept of self-compacting concrete (SCC) and high-performance concrete (HPC). HPSCC combines the rheological properties of SCC (resistance to segregation, flowing under its own weight, form filling without extra compression) and the durability and good strength performance of HPC. Such parameters require a preparation of a specific content and ingredient proportions. An HPSCC mix, as compared to an ordinary concrete mix, is characterized by an increased content of Portland cement, superplasticizers and reactive mineral additives, most often in the form of silica fume [3,4,5].

The properties of an HPSCC mix allow tight form filling accompanied by venting and self-levelling without additional mechanical compression. The ability of HPSCC to flow over much larger distances than vibrationally-compacted concrete enables a reduction of the number of mix casting points when making a concrete element [6]. It is possible to fill a formwork from a single casting point (beams, deep beams) or to reduce the number of casting points by waiting until concrete has spread as far as possible before moving to another casting point (e.g. slabs, walls). Given the satisfactory resistance to segregation of properly engineered HPSCC mixes, one might suspect that following the concreting methods presented above should lead to a uniform strength performance throughout the element produced. However, there are no scientific publications providing evidence for this hypothesis. This work is an attempt to assess the changes in the strength properties of new generation HPSCCs in elements made by casting a concrete mix from the top of a mould from a single casting point at one edge of the elements.

2. Scope of research

The author of this study has attempted to assess the changes in the strength properties of concrete along the length and height of monolithic deep beams made of HPSCC. Specifically, the compressive strength variations are examined. In the study, a variant is considered in which casting is carried out from the top of a mould from a single casting point at one element's edge. Ninety cubic samples that were used in the tests had been cut out of deep beams made from three different HPSCC mixes. Compressive strength tests were conducted according to EN 12390-3 [7]. The tests were done after 28 days of concrete curing in laboratory conditions.

3. Experimental program

3.1. Concrete mixtures

The study was performed on elements made of three HPSCC mixtures in which the amount of silica fume differed (0, 5 and 10% of cement mass), replacing part of the concrete. However, the binder content (550 kg/m^3) and the water-binder ratio (0.32) were the same. The composition of the mixes was developed based on the author's own experiences and work guidelines [3,4,5,8]. The characteristic properties of the concrete mixes are given in table 1.

Table 1. Composition by mass of proposed mixes

Composition [kg/m^3]	Recipe denotation		
	HPSCC-0	HPSCC-5	HPSCC-10
Cement CEM I 42.5R	550	524	500
Water	176	176	176
Sand 0/2 mm	790	790	790
Basalt aggregate 2/8 mm	940	940	940
Silica fume	–	26	50
Superplasticizer	5.14	5.98	6.27
Water/binder ratio	0.32	0.32	0.32
Silica fume level	0%	5%	10%

3.2. Description of specimens

In this study, three deep beam-type study elements were used with dimensions of 1.50 x 0.15 x 0.45 m (length x width x height). Each research element was designed so that its dimensions were multiples of the dimensions of a norm cubic sample (0.15 x 0.15 x 0.15 m) according to EN 12390-3 [7]. Concreting was conducted from the top of a formwork from a single casting point at one edge of each element. Concreting was performed continuously until the formwork was filled completely. For each HPSCC mixture one test element was produced. A schematic view of a test element is shown in figure 1.

The concreted deep beams were next left in their formworks for 3 days. After formwork stripping, the specimens were kept in a laboratory room in unchanged positions. In the time preceding tests, the elements were protected against vibrations and were being cared for by water spraying. After 21 days, the specimens were cut into elementary parts. Additionally, for each HPSCC, 5 cubic reference samples were made according to [7].

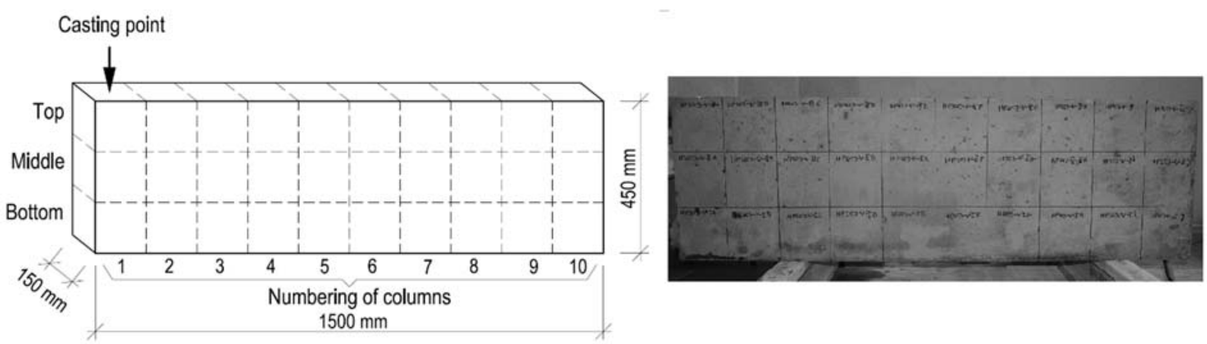

Figure 1. A schematic view of a test element

4. Results and discussion

Table 2 presents the rheological properties of the concrete mixes and the average values of the compressive strength of the reference samples. Figure 2 shows the changes of the compressive strength along the study elements. In turn, figure 3 shows the changes of the compressive strength ratio along the elements, defined in a given layer as the ratio of the compressive strength of the sample considered to the sample situated at the casting point ($f_{c,i}/f_{c,1}$).

Table 2. Details of concrete mixes

Mix Symbol	Slump flow [cm]	Slump flow class	Slump flow time T50 [s]	Viscosity class	L-box ratio	L-box	Fresh visual stability index	Compressive strength	
								f_c [MPa]	Cov [%]
HPSCC-0	69	SF2	1.7	VS1	0.94	PL2	0	81.5	4.6
HPSCC-5	72	SF2	2.1	VS2	0.89	PL2	0	85.7	5.3
HPSCC-10	66	SF2	2.3	VS2	0.91	PL2	0	87.4	7.1

Table 3. Test results

Mix symbol	Compressive strength [MPa]												
	Sample	1	2	3	4	5	6	7	8	9	10	Mean	Cov
HPSCC-0	Top	78.5	79.8	77.1	80.1	81.0	77.4	79.2	79.1	76.6	75.5	**78.4**	**2.1%**
	Middle	82.4	85.5	80.1	84.0	82.1	84.0	82.7	83.2	81.5	82.6	**82.8**	**1.7%**
	Bottom	92.1	94.2	91.5	90.1	91.5	87.1	87.5	84.4	85.5	86.0	**89.0**	**3.5%**
HPSCC-5	Top	84.9	84.1	83.4	84.6	85.0	80.4	82.5	80.9	80.8	79.2	**82.6**	**2.5%**
	Middle	88.9	86.6	91.1	86.2	89.1	88.7	83.5	82.7	81.5	86.1	**86.4**	**3.4%**
	Bottom	94.6	94.1	92.5	90.2	90.6	88.3	91.1	89.1	89.6	90.2	**91.0**	**2.2%**
HPSCC-10	Top	88.0	87.0	87.0	85.4	83.1	85.3	86.2	82.7	85.0	83.9	**85.4**	**2.0%**
	Middle	92.7	90.6	87.8	88.2	87.0	90.7	87.5	85.4	87.4	88.1	**88.5**	**2.3%**
	Bottom	95.6	96.9	93.4	92.2	93.1	95.2	94.4	92.1	89.0	91.5	**93.3**	**2.3%**

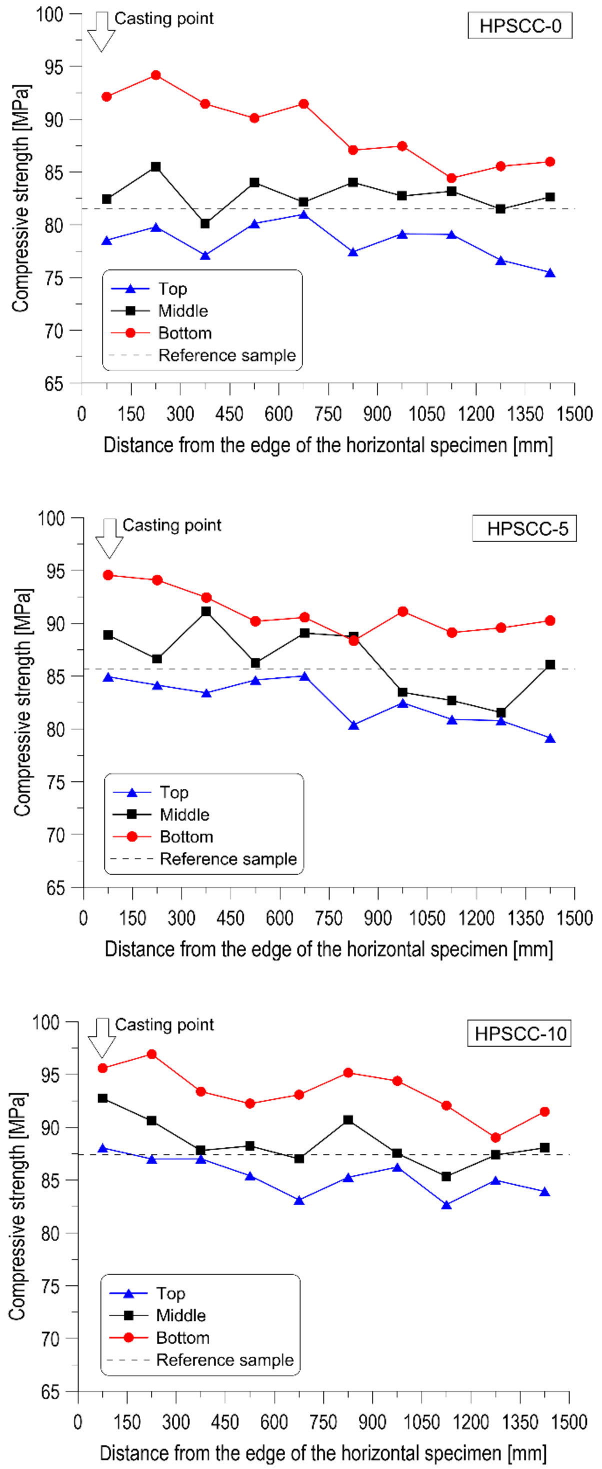

Figure 2. Compressive strength as a function of specimen position

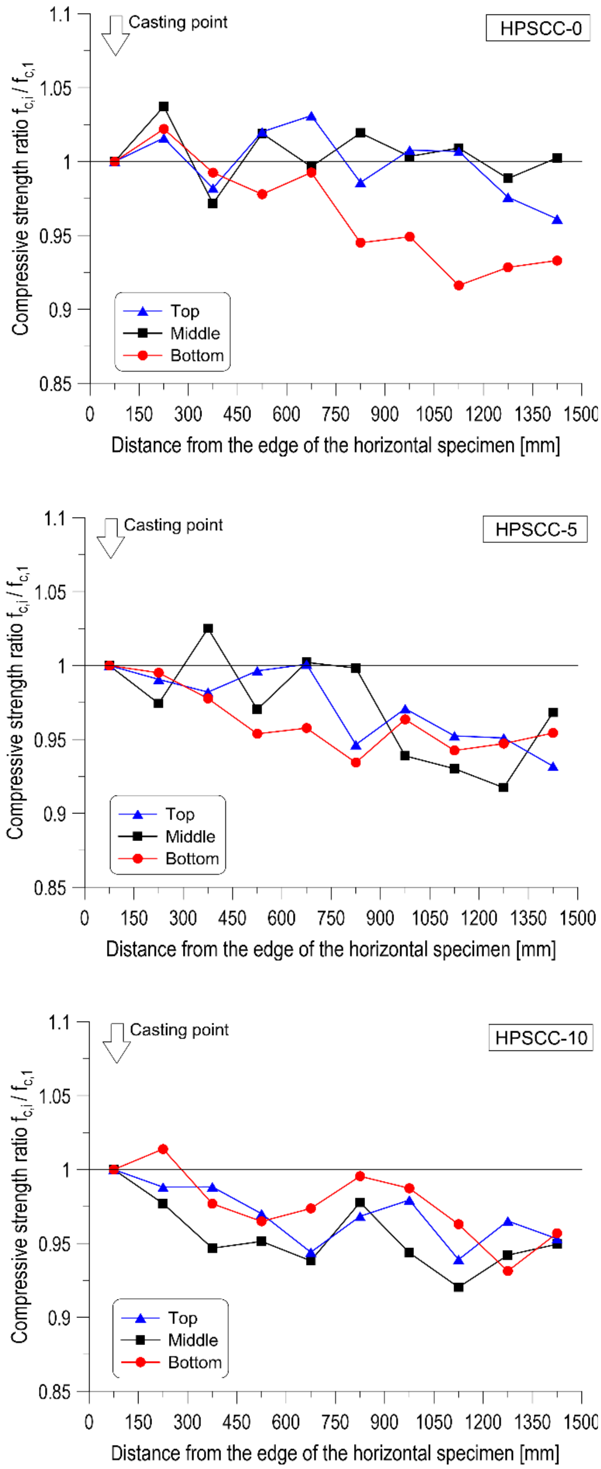

Figure 3. Variation of compressive strength ratio along the lengths of the elements

The studies conducted showed that the compressive strength was practically constant along the elements. This observation was independent of the elements' layer considered (top, middle, bottom). The coefficient of variation of the compressive strength (Cov) for all the HPSCC mixes used in the experiment was in the range 1.7-3.5%. Moreover, the study revealed an agreement between the compressive strength distribution and the concrete volume density distribution along the elements see table 3.

The HPSCC mixes used in the experiment did not exhibit statistically important differences in terms of the compressive strength along the specimens. However, a tendency was observed in which the compressive strength was reduced with the distance of samples from the casting point. The maximum reduction of the compressive strength along the element was 8% for each concrete mix. The changes of the compressive strength observed in the three layers analysed - top, middle and bottom - were similar.

What is more, an increase of the compressive strength was observed for the samples in the bottom and middle layer situated at the edge opposite the concrete casting point. Based on this observation one may conclude that in that region there was a positive effect of extra mixing of the concrete due to its bounce off the formwork. This effect did not take place in the upper layer given the deliberate slowing down of the mix spreading as it was necessary to level up the concrete with respect to the top of the formwork.

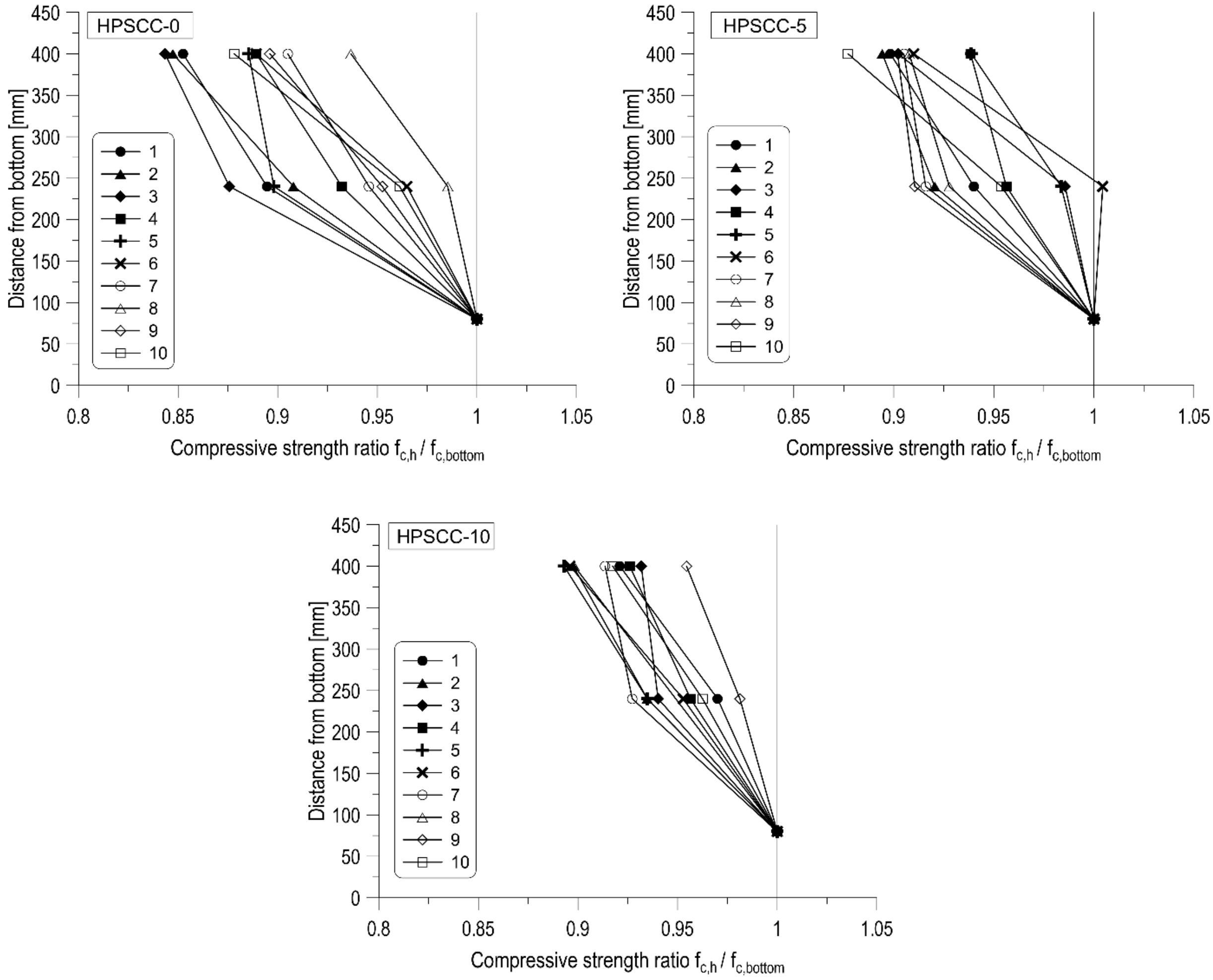

Figure 4. Variation of the compressive strength ratio along the heights of the elements

The compressive strength values obtained for the samples cut out of the study elements were compared with the compressive strength measured in the reference samples made according to [7] (figure 2). Only the samples in the upper layer of the study elements exhibited lower values of the compressive strength than in the case of the reference samples. This was true independent of the HPSCC considered. The maximum difference in the compressive strength was 8%. This is caused by a higher degree of the mix consolidation in the normed samples comparing to the upper layer in the wall elements.

It was demonstrated that the compressive strength of the concrete was reduced with an increase of the distance from the bottom of the formwork. Independently of the distance from the mix casting point and the concrete type used, in the upper part of the study elements a lower quality concrete zone was formed. Figure 4 shows the course of the changes of the compressive strength ratio along the height of the elements ($f_{c,h}/f_{c,bottom}$). The reduction of the compressive strength in the samples from the top layer with respect to the samples from the bottom layer in a given column was in the range 6-16% for HPSCC-0, 6-12% for HPSCC-5 and 5-11% for HPSCC-10. A relation between the change of the compressive strength along the height of the elements and the distance of the samples from the concrete mix casting point was not observed. This is connected to a tendency of a uniform compressive strength reduction along the elements both in their upper and lower part.

The underlying physical mechanism of the compressive strength reduction along the height of the elements is a result of a specific form of segregation related to self-draining of free water. The potential entrapment of bleed water underneath coarse aggregate particles can be expected to increase towards the top of the deep beams. Such bleeding can weaken the interface between the aggregate and cement paste and result in a reduction of compressive strength. The modified micro-structure and different rheological properties of HPSCCs cause that the reduction of the compressive strength in the top layers of the elements is lower than that reported in scientific studies on ordinary concretes [9].

5. Conclusions

The main scope of the present study was the compressive strength variation along the length and the height of monolithic deep beams with a single casting point at one edge. The following conclusions can be drawn from the results of this experimental work:

- Statistically insignificant differences were obtained between the variations in the compressive strength values along the 1.50 m-long deep beams made of HPSCC mixtures. In general, the variations in the compressive strength along the length of the experimental elements were limited to 8%.
- It was demonstrated that in the top parts of the study elements a zone formed in which the quality of the concrete was lower irrespectively of either the distance from the mix casting point or the HPSCC content used. In the experiment, the reduction of the compressive strength along the test elements was in the range 5-16%.
- Casting the HPSCC mix from a single casting point at one element's edge gave a satisfactory degree of uniformity of the strength distribution in the study elements. This variant of casting may be used in practice as an alternative way of laying an SCC mix.

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