WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2026.1385

ARCHIVES OF CIVIL ENGINEERING

Vol. LXXII ISSUE 3 2026

pp. 241 –255

Research paper

Bottom-up casting of self-compacting concrete as a factor improving steel-concrete bond strength

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Abstract: This study investigates the impact of bottom-up casting on the bond behaviour between reinforcing steel and self-compacting concrete in full-scale structural wall elements. Through experimental pull-out tests and X-ray computed tomography, a comparison is made between bottom-up casting and the conventional top-down method. A wall-type test element measuring 2240 × 1600 × 160 mm was designed for the study. The results obtained from this study demonstrate that bottom-up casting technology significantly enhances bond strength, showing a 10% increase in normalised bond strength. This improvement in bond strength is attributed to enhanced consolidation and deaeration of the mix during the casting process, which serves to minimise defects such as air voids. Additionally, the bottom-up method leads to more uniform bond distribution along the height of the wall, thereby reducing the top-bar effect commonly seen in top-down casting. Tomographic scans revealed a reduced presence of air voids in the cover zone of bottom-up cast elements, providing further evidence of superior material compaction. The study concludes that bottom-up casting holds promise for improving SCC element performance, especially in applications where bond quality and uniformity are critical.

Keywords: bond, bottom-up casting, new generation concretes, self-compacting concrete, technological factors, top-bar effect

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1. Introduction

Self-compacting concrete (SCC) has been shown to achieve adequate compaction without the use of vibration, due to its special mix design. Its composition relies on a number of factors to enhance both fluidity and stability: a reduced proportion of coarse aggregates to limit the contact between the aggregate particles, a lower water-to-binder ratio (w/b) which increases the viscosity of the paste, and the application of a superplasticizer to increase the workability. The primary benefits of SCC are attributed to its high level of tightness, durability and resistance to aggressive conditions compared to normal concrete when properly prepared [1]. Consequently, a structure made using SCC has lower maintenance costs, mainly due to the reduction in the need for costly repairs and corrections.

Due to their fluidity, self-compacting mixes are well suited to placement by means of pumping, and this method is therefore the most widely used [2]. A casting method that is unique to these mixes is to pump them through valves placed at any height of the formwork, most notably at the bottom of the formwork (bottom-up casting method). The configuration of these valves varies according to the manufacturer of the formwork. In some instances, the valve is a permanent fixture affixed to the mould wall, while in others, it is a portable valve that can be inserted into a drilled opening in the formwork. Bottom-up casting of the mix enhances self-deaeration, which consequently results in a better surface finish, making it particularly recommended for column and wall elements as well as tunnel lining [2]. The method requires continuously pumping the mixture at high velocity, enabling faster element execution and minimizing the risk of segregation, thereby enhancing its mechanical properties [3]. However, bottom-up casting of SCC is known to exert higher pressures on the formwork due to its non-thixotropic behaviour from continuous movement, necessitating additional reinforcement [4, 5].

The studies cited above on the advantages and disadvantages of self-compacting mix casting technology did not address the issue of bond to reinforcing steel. However, if bottom-up casting indeed promotes more efficient venting and consequently greater homogeneity of the concrete, then it can be assumed that this technology will improve the quality of rebar cover. Investigations into the effect of bottom-up casting on the improvement of steel-concrete bond phenomenon were initially identified for column and beam elements made of high-performance self-compacting concrete (HPSCC) [6, 7] and normal strength SCC [8]. In both beam element studies, the mixture was delivered from a single casting point, located at the end of the formwork. The rebars were positioned at two levels within the element: near the bottom and near the top surface. This was done in order to simulate the zones of good and poor bond conditions, as outlined in Eurocode 2 [9]. The bottom-up casting technology exhibited a favourable effect on the bond properties along both the height the beam and column elements. The increase in bond strength of the rebars placed at the top of the element was found to be, on average: 19.7% for normal strength SCC mixes, 15.5% for HPSCC without silica fume and 7.4% for HPSCC mixes with silica fume compared to traditional casting technique. For rebars placed in the bottom layer, altering the casting direction had no significant effect on the bond results obtained, regardless of the concrete mix used. High bond stresses were consistently observed in the bottom parts of all tested elements. Furthermore, analysis of the rebar-concrete interface after pull-out tests demonstrated that bottom-up casting of SCC resulted in a reduction in the number of air bubbles in the contact layer and limited the settlement of the mix under the top rebars. An improvement in the quality of the concrete cover for SCC, manufactured using bottom-up casting technology, was also observed in X-ray computed tomography (X-ray CT) studies on core samples extracted from panel elements [10, 11]. This technique eliminated the occurrence of air voids and settlement of the mix under the top reinforcing bars. The uniform quality of the concrete cover around the rebars reduced the stress concentration at the rebar-concrete interface and improved the uniformity of the stress distribution.

The present study aims to confirm the observed relationships for wall elements of much greater size than those used in previous research. It should be noted that all previous studies have been carried out on short elements of 48 cm in height. This will verify the assumptions regarding zones of good and poor bond conditions. According to the EN 1992 standard guidelines [9], the zone of poor bonding conditions is assumed to be 30 cm below the top surface of the element, unless the height of the element does not exceed 60 cm, in which case the zone of good bond conditions is located up to 30 cm from the bottom of the mould.

2. Materials and methods

2.1. Materials

A self-compacting concrete mix, designed and supplied by a leading ready-mixed concrete manufacturer, with a declared compressive strength class of C35/45, was used to prepare the test elements. The casting process was executed in two cycles, utilising the same mix composition. The batches were designated with the letters A and B. The composition of the mix was based on blast furnace cement CEM III/A 42.5N – LH/HSR/NA. In each case, the product met the requirements of EN 197-1 [12]. The natural aggregate used was composed of sand (grain size 0–2 mm), and gravel (2–8 mm and 8–16 mm). The aggregate content was established at 1718 kg/m3, with the sand point set at 39%. The aggregates complied with the requirements of EN 12620:2010 [13]. Fig. 1 presents the grain size curves for the aggregates, as provided by the ready-mix concrete manufacturer. The composition of the concrete mixture is outlined in Table 1.

The investigations were carried out on elements with embedded deformed rebars of 16 mm diameter, made of class B500SP reinforcing steel. The rebars met the requirements of EN 10080 [14]. The bar diameters used are representative of the so-called medium diameters (10–20 mm). The reinforcement was in production condition (i.e. free of loose mill scale and rust) and was delivered each time before the concrete work.

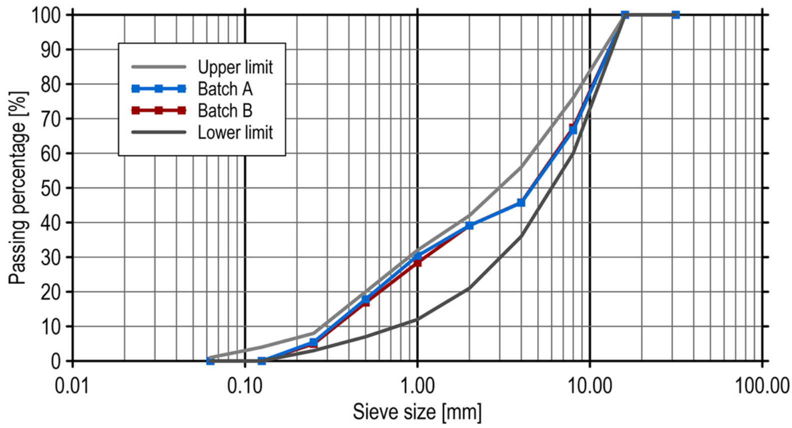


Fig. 1. Gradation curves of fine and coarse aggregates of both SCC batches

Table 1. Composition of self-compacting mixture per 1 m^3

Component	Unit	Quantity
Cement CEM III/A 42,5N – LH/HSR/NA	kg	440
Tap water		160
Sand 0–2 mm		684
Gravel 2–8 mm		510
Gravel 8–16 mm		560
Chemical admixtures		
Superplasticizer	% of cement mass	1,1
Plasticizer		0,5

2.2. Test elements

In order to confirm the effect of bottom-up casting technology on the bond between reinforcing steel and self-compacting concrete, a wall-type test element measuring 2240 × 1600 × 160 mm was designed (Fig. 2). The configuration of the test element included 140 modular samples, with 32 allocated for bond testing and 10 for X-ray CT analysis, distributed over the height and length of the element. The remaining samples were dedicated to compressive and splitting tensile strength tests. The modules for each test are shown schematically in Fig. 3. Two casting technologies were employed in the manufacture of the test elements: traditional top-down (TD-W) and bottom-up (BU-W). The bottom-up casting technology was ensured by a valve fixed in the formwork. To ensure proper deaeration of the SCC mix, one casting point was established. The element was subsequently marked with dividing lines corresponding to columns with capital letters from A to N, and rows (layers) with numbers from 1 to 10. The location of the casting point was consistent, situated at one edge of the element within a column A. During the concrete curing period, the formwork remained static, while the surface of the elements was kept permanently moist and protected from drying out by a membrane, in accordance with EN 13670 [15]. After 28 days of curing, the elements were cut into smaller cubic or core samples that were subsequently subjected to testing.

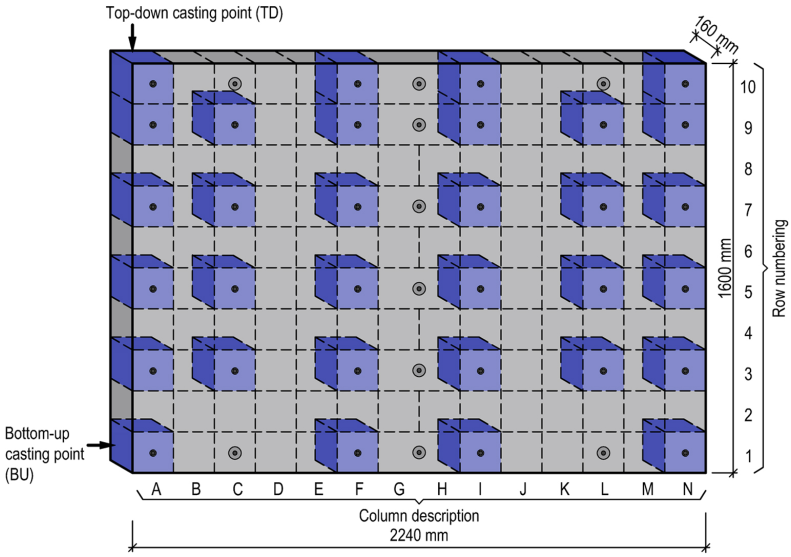


Fig. 2. Wall element schematic view

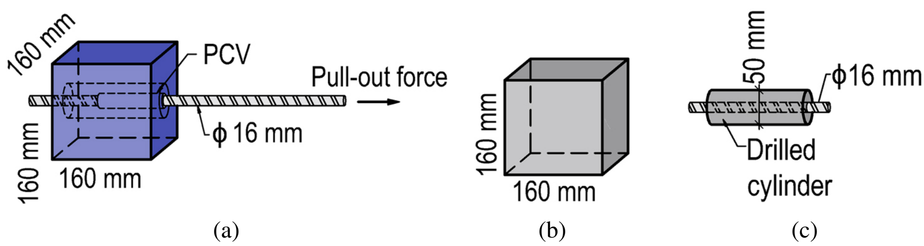


Fig. 3. Types of modules in experimental programme; (a) pull-out test module, (b) compressive and splitting tensile strength test module, (c) X-ray CT module

2.3. Experimental procedures

2.3.1. Concrete strength properties

In order to assess the mechanical properties of the concretes, a series of compressive strength and splitting tensile strength tests were carried out on cubic modules taken from the test elements. The compressive strength of the concrete specimens was investigated in accordance with EN 12390-3 [16]. The splitting tensile strength of concrete specimens was determined in accordance with EN 12390-6 [17]. The dimensions of the specimens were measured immediately prior to the testing. For each side of the cube, the final dimension was taken as the average of three individual measurements, recorded with an accuracy of 1.0 mm.

2.3.2. Pull-out test

Out of various method of bond testing, the pull-out test was employed, pull-out test was the selected method, as it is recommended by both RILEM [18] and EN 10080 [14]. This is a primary method for the bond between rebars and concrete evaluation given their various properties and types. The test involves the application of a tensile load to the bar anchored in a concrete block. The measured data refers to the load applied to the bar and the relative slip between steel and concrete. The use of elements with a short bond length (defined as 2.5 times the rebar diameter) permits the assumption of a linear distribution of deformation along the bar axis. Under this condition, the bond stress is considered uniform and can be determined analytically using Equation (2.1):

$$\tau = \frac{F}{\pi d L} \tag{2.1}$$

Where: F – the applied pull-out load, d – the bar diameter, L - the bond section length.

The bond section length was adopted as $2.5d$ (40 mm) in the experimental programme. The required bond section length was achieved by means of plastic tubes (PVC) inserted around the concrete-immersed part of the rebars. The pull-out load was then applied gradually until the point of bond failure was reached. The resultant slip of the unloaded rebar end was measured using two linear variable displacement transducers (LVDTs) operating in connection to a data collection piece of software.

To provide a comparison of the bond properties throughout the wall elements, the authors used the so-called ultimate bond stress τ_max (bond strength) as an unambiguous quantity, defined as the bond stress at the moment of bond failure.

The impact of difference in concrete strength (both compressive and tensile) between batches on the bond phenomenon was considered, with the analysis of bond results conducted post-normalisation. The normalisation of the bond stresses against the square root of compressive strength was employed, in accordance with standard practice. The average value of the compressive strength of a given element was used for the normalisation.

2.3.3. X-ray CT

The core samples were examined using a GE Phoenix v|tomex|m X-ray CT system. During the X-ray CT investigation, the sample is located between the radiation source and the detector. A 300 kV mini focus tube was used to emit X-rays with sufficient energy to penetrate the reinforced concrete specimen and hit the detector. Visualisation of the internal structure in 2D images with a resolution of 0.05 mm/pixel was possible by detecting density changes in the element and was inferred from the X-ray intensity. All samples were scanned with constant scanning parameters. During one scan, 1800 images were produced, and the process lasted approximately 90 minutes.

Subsequently to the X-ray CT scans, the reconstruction process was made. It consists of a combination of the series of 2D images into a 3D model using a dedicated piece of software. The reconstructed 3D model was analysed in order to find and examine air voids around the rebar. Porosity analysis was performed using Volume Graphics software: VGSTUDIO MAX, in a Region of Interest (ROI) narrowed to the vicinity of a rebar.

3. Results and discussion

3.1. Fresh mix and concrete properties

The filling ability tests (slump flow and $T50$ spread time), the passing ability tests (L-box) and the segregation resistance tests (VSI) were conducted to assess the fresh properties of each batch of SCC. The tests were conducted in situ, prior to casting in the formwork. Despite the uniform composition of the self-compacting mixes, slight differences were observed between them. However, both mixes met all the criteria for self- compacting mixes: flowability, ability to pass through narrow openings and stability. The detailed results of fresh mix properties are outlined in the Table 2.

Table 2. Flow properties of SCC mixes

Batch	Slump flow [mm]	Slump flow time up to 500 mm diameter [s]	L-box ratio	Visual Stability Index
A	660	4	0.88	0
B	645	5	0.85	1

Tests of strength properties on samples taken from the test elements were carried out 40 days after concreting. The timing of the compressive and splitting tensile strength tests was synchronised with the bond tests and determined by the technological process of cutting the modules from the major test elements. The mean outcomes of the investigations for the individual elements are shown in Table 3.

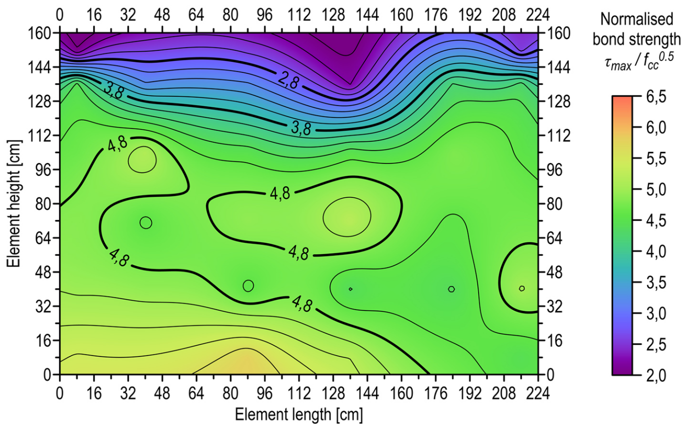
Table 3. Compressive and splitting tensile strength test results

Batch series	Element	Mean	Number of samples	Standard deviation	Coefficient of variation
		$\overline{x}$ [MPa]	n [–]	SD [MPa]	CV [%]
Compressive strength					
A	BU-W	63.05	68	7.52	11.93
B	TD-W	74.30	68	7.90	10.64
Splitting tensile strength					
A	BU-W	3.44	24	0.61	17.80
B	TD-W	4.02	24	0.64	16.02

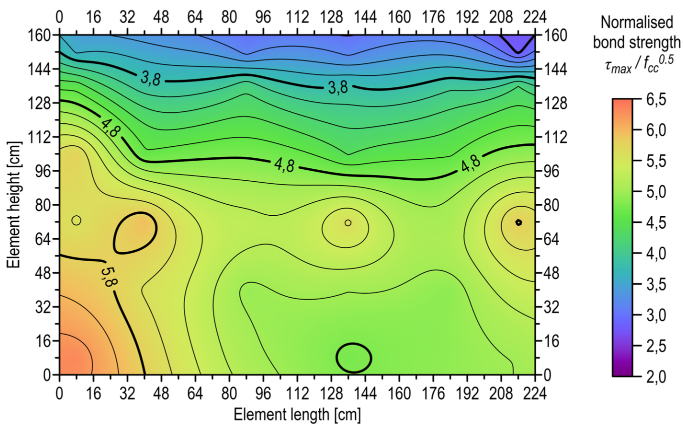
3.2. Bond properties

3.2.1. Normalised bond strength

In order to neutralize the differences between SCC batches on the bond test results, the analysis applied a commonly used normalisation of bond stresses to the square root of the mean compressive strength [19]. Given the absence of a clear trend in the variation of compressive strength along the height and length of the elements, the mean value from tests on specimens cut from the respective element was adopted for normalisation. The findings of the bond tests have been presented in Fig. 4 in the form of maps illustrating the approximate distribution of the normalised bond strength within the entire wall type elements. The distribution map is presented as a colour map, with accompanying isolines. The colour scale was uniform for both elements. The pitch of the isolines was set at 0.2.



(a)



(b)

Fig. 4. Normalised bond strength distribution map within wall elements: (a) TD-W, (b) BU-W

The normalised ultimate bond stresses in a wall element cast from the bottom (BU-W) are, on average, 10% higher than those in an element cast using the traditional mix casting technique (TD-W). Furthermore, the coefficient of variation of bond strength values in the BU-W element is reduced to 18.3% compared to 23.5% in the TD-W element; suggesting that the bond conditions in the former are more uniform.

In the TD-W element, relatively uniform bond conditions prevailed up to a height of approximately 120 centimetres (values of normalised bond strength between 3.8 and 5.6). Beyond this level, values decreased drastically, reaching a minimum of 2.0 at the top part of the element. This is a exemplary representation of the change in bond conditions proposed in Eurocode 2 [9]. In contrast, in the BU-W element, the transition between good and poor bond condition zones is less abrupt. A more significant decrease in the normalised bond strength was only noticeable in the highest row of bars (10) and was less pronounced than in the TD-W element (up to a value of 2.8). However, the distribution of bond strengths in the lower and middle part of the BU-W wall is less uniform than in the TD-W element (values between 3.8 and 6.2), primarily due to the increase in bond stresses in the region of the mix casting point. The sustained pressure exerted by the mix on the rebars in column A, extending up to the third row during the concreting process, resulted in the tightening of the cover structure and, consequently, an enhanced bond at the interface between the two materials.

3.2.2. Bond-slip relationships

Figure 5 demonstrates the relationship between normalised bond stress and rebar slip for a selection of specimens derived from wall-type elements located in the zone of good and poor bond conditions. Samples derived from row 1 of wall elements were selected as representative for good bond conditions. Whereas for poor bond conditions, all specimens in their zones - rows 9 and 10 – are shown on the graph.

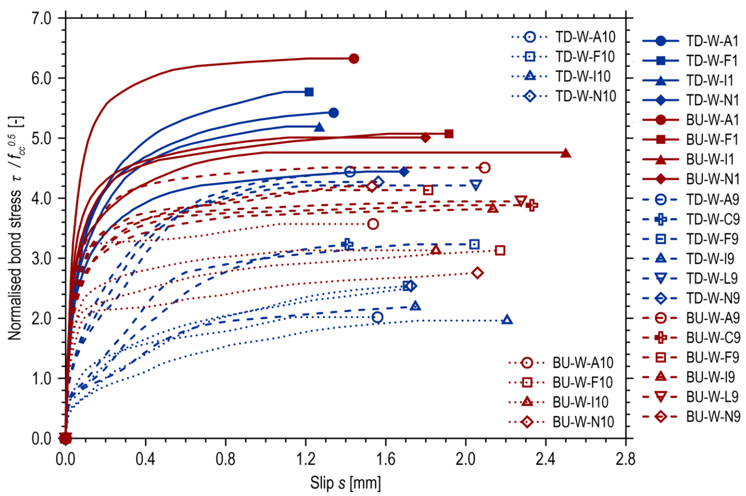


Fig. 5. Bond-slip relationships in good and poor bond conditions zones according to EC 2

The bond-slip curves of specimens in good and poor bond conditions differ in their course in both elements. However, the discrepancy in these variations in the element made with the bottom-up casting technology is less pronounced.

The $\frac{\tau}{{f_{cc}}^{0,5}} - s$ curves for the rebars located in good bond conditions in their course are similar in both elements. However, in the zone of poor bond conditions, a marked difference can be seen in both the course and slope of the curves when comparing the elements made with two mix casting technologies. For rebars in the ninth row of the BU-W element, a slightly smaller inclination of the curve was observed in the initial phase of slip up to 0.1 mm (bond stiffness) when compared to rebars located in good bond conditions. Conversely, in the TD-W element, the bond stiffness of the corresponding rebars underwent a substantial decrease. However, these differences in some of the specimens (A9, L9 and N10) disappeared at normalised bond stresses corresponding to a slip of more than 0.5 mm, and the final values of the normalised bond strength of the two elements were comparable. The differences in the bond-slip curves of the rebars in the 10th row of both technologies were amplified compared to the 9th row. The bond-slip curves of the specimens in the 10th row of the TD-W element were distinguished by the greatest inclination angle within the range of minor slip (up to 0.1 mm) in both elements.

The increased bond stiffness is indicative of improved concrete quality beneath the ribs of the rebar. Consequently, the pull-out force required to displace a section of rebar must be greater.

3.2.3. Top-bar effect

A phenomenon commonly encountered in tall reinforced concrete structural elements is the deterioration of the bond conditions in their upper region, known as the top-bar effect. This phenomenon is associated with adverse processes that occur in the cover of the reinforcing bars, such as bleeding and plastic settlement. The international standard guidelines have been found to take this into account in the form of casting position factors for rebars.

A comparison of the mean value of the casting position factor as determined for the bond strengths in each row with the results from literature studies is shown in Fig. 6. The casting position factor k_{cp} dedicated to bars in poor bond conditions shows the necessity of elongation of the calculated anchorage length for these bars. It is defined as the inverse value to of the ratio of the tested values of bond strength: bond strength of the bar located in the distance x from the bottom – $\tau_{\max,x}$ – to the bond strength of the bottom bar – $\tau_{\max,\text{bottom}}$:

$$k_{cp} = \frac{1}{\dfrac{\tau_{\max,x}}{\tau_{\max,\text{bottom}}}} = \frac{\tau_{\max,\text{bottom}}}{\tau_{\max,x}} \tag{3.1}$$

For the purpose of comparison, wall type elements were considered, which were produced both by the traditional mix casting technology [20–22] and by bottom-up casting of SCC [23]. Given the varying heights of the test elements in the literature studies, the comparison of the casting position factors was performed depending on the distance of the bars level from the top of the element. It is noteworthy that some of the elements found in the literature studies were designed such that the bars located at the highest level of the element were not within the poor bond conditions defined in Eurocode 2 [9].

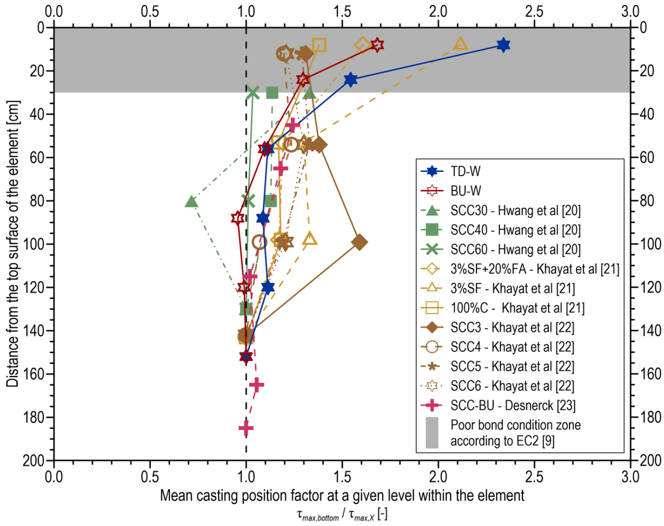


Fig. 6. Casting position factor in wall type elements

In the present research programme, the top bar effect was observed in both elements but was considerably reduced in the element made using the bottom- up casting technology. The mean casting position factor in the top row was 18% lower in the BU-W element than the mean casting position factor in the TD-W element.

A comparison of the values of the casting position factor in the elements produced using top-down casting technology reveals that the highest values were observed for the TD-W element in the zone of poor bond conditions. However, it is noteworthy that the elements examined by Khayat et al. [21, 22] had significantly smaller spans than the element produced in this research programme. Moreover, Hwang et al. [20] designed elements in which the top bars were positioned at the border between good and poor bond conditions according to Eurocode 2 [9], with the bottom bars situated 30 cm from the bottom. That arrangement of rebars resulted in lower values of the casting position factor, as bars in closer proximity to the element's centre were compared. When all these factors are taken into consideration, it can be concluded that the TD-W element performed in this research programme does not differ significantly from the results reported in the literature.

An analysis of the casting position factor in elements produced using the bottom-up casting technology reveals that the results for both elements (BU-W and the one produced by Desnerck [23]) in the zone of good bond conditions are similar. However, it should be noted that in the sole literature source that utilised this technology to assess the steel-concrete bond, the rebars positioned within the zone of poor bond conditions were not designed.

3.2.4. Effect of bottom-up casting of SCC

In general, the technology of casting the SCC mix from the bottom of the formwork had a beneficial effect on the bond strength values, particularly in the near-surface zone of the elements – thus in the zone of poor bond conditions. Furthermore, within the BU-W element, the bond stiffness decreased only noticeably for the rebars closest to the surface of the element (row 10). Conversely, rebars in row 9, which are also categorised as poor according to Eurocode 2 [9], exhibited bond stiffness comparable to that in the good bond condition zone.

The beneficial impact of the bottom-up casting of self-compacting mixture technology is attributable to the improvement in the microstructure of the concrete cover around the rebars in the upper part of the elements, which has been experimentally verified by tomographic studies (Fig. 7).

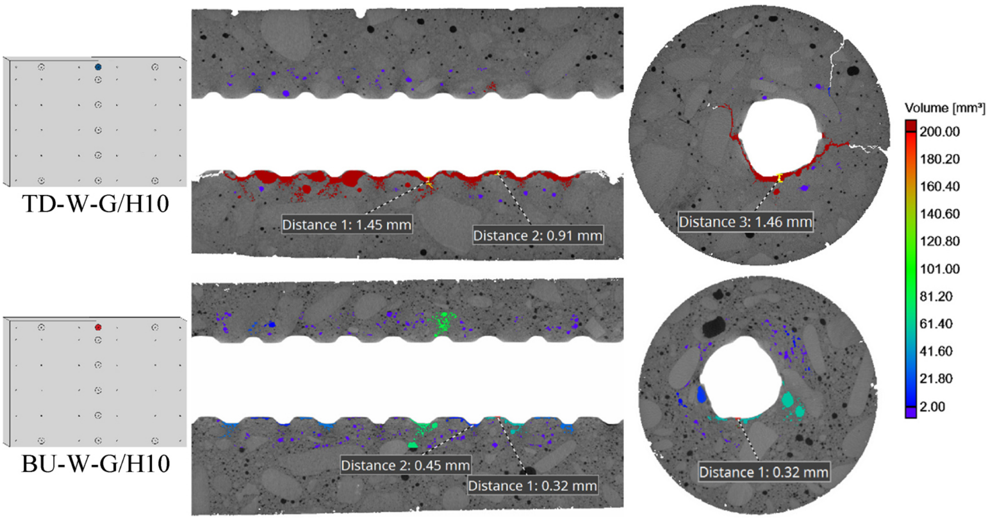


Fig. 7. Comparison of tomographic sections of core samples extracted from the poor bond condition zone of both test elements

Irrespective of the casting technology employed, voids resulting from mixture settlement and bleeding phenomena are observed under the rebars located in poor bond conditions. However, the volume of these voids is significantly larger in the TD-W element. An analysis of the cover surrounding the rebars in the uppermost (10th) row reveals that the settlement directly beneath the ribs was a maximum of 1.45 mm in the TD-W element, 0.45 mm in the BU-W element, and 0.91 mm and 0.32 mm in the space between the ribs for the TD-W and BU-W elements, respectively. Furthermore, it was observed that, beneath the rebar of the TD-W element, the air pores and voids that had formed due to bleeding and plastic settlement phenomena merged into a single discontinuity, resulting in the exclusion of the lower ribs from load transfer.

It was observed that the size of the voids is generally slightly larger in the space immediately below the ribs than in the inter-rib zone. This tendency can be explained by the less effective adhesion of the mixture associated with the geometry of the ribs, which favours the slippage of the mixture in the area under consideration, as noted in analogous tests on panel elements of self-compacting concrete [10]. These observations are of particular value when considered in the context of studies on normal and self-compacting concretes, which demonstrated that the bond phenomenon between the ribbed reinforcing bar and the concrete is most influenced by the size of the void in the area between the ribs [24].

4. Conclusions

The present study investigated the impact of bottom-up casting on the bond behaviour between reinforcing steel and self-compacting concrete (SCC) in full-scale wall elements. The findings of the study highlight several key advantages of this casting method:

- Bottom-up casting of SCC resulted in an improvement in normalised bond strength when compared to traditional top-down casting. On average, a 10% increase in normalised bond stress was observed for the bottom-up cast elements (BU-W).
- The coefficient of variation of bond strength values was significantly lower in the bottom-up cast elements (18.3%) than in the top-down cast elements (23.5%), indicating a more uniform distribution of bond quality throughout the height of the wall. The smoother transition between zones of good and poor bond conditions further confirms the homogenizing effect of bottom-up casting.
- The top-bar effect was significantly reduced in elements cast from the bottom. The average casting position factor in the uppermost reinforcement layer was 18% lower in the BU-W element compared to the TD-W element. This reduction can be attributed to enhanced self-deaeration and reduced air entrapment at the rebar-concrete interface.
- The bond-slip relationships demonstrated exhibited bond stiffness in the bottom-up cast elements, particularly in the case of poor bond condition zones. This is indicative of improved concrete quality around the rebar and more effective load transfer under service conditions.
- X-ray CT scans confirmed the reduced extent of negative phenomena in the cover beneath rebar of the BU-W element, supporting the observed improvements in bond strength and bond stiffness.

In summary, bottom-up casting of SCC presents a promising technique for enhancing the steel-concrete bond, promoting more reliable and durable structural performance, especially in elements subjected to complex loading and durability requirements.

Acknowledgements

This work was supported by the National Science Centre, Poland [grant number: 2023/49/N/ST8/01835]. For the purpose of Open Access, the author has applied a CC-BY public copyright licence to any Author Accepted Manuscript (AAM) version arising from this submission. Moreover, the authors would like to express gratitude to the Steel Quality Promotion Centre (CPJS) for the material support.

References

[1] G. De Schutter, P.J.M. Bartos, and P. Domone, *Self- Compacting Concrete*. Dunbeath: Whittles Publishing, 2008.

[2] “The European Guidelines for Self Compacting Concrete: Specification, Production and Use”, EFCA [Online]. Available: https://www.efca.info/download/european-guidelines-for-self-compacting-concrete-scc/.

[3] G. De Schutter, D. Feys, and R. Verhoeven, “Ecological Profit for a Concrete Pipe Factory due to Self-Compacting Concrete Technology”, in *Second International Conference on Sustainable Construction Materials*

and Technologies, J. Zachar, P. Claisse, T.R. Naik, and E. Ganjian, Eds. University of Wisconsin-Milwaukee Centre for By-products Utilization, 2010, pp. 1281–1287.

[4] S. Tichko, et al., "Influence of the viscosity of self- compacting concrete and the presence of rebars on the formwork pressure while filling bottom-up", *Engineering Structures*, vol. 101, pp. 698–714, 2015, doi: 10.1016/j.engstruct.2015.08.008.

[5] X. Lu, W. Zhang, L. Xu, and Y. Chen, "A lateral pressure prediction model for bottom-up pumping of SCC in large-diameter steel tubes based on Bernoulli's Principle", *Case Studies in Construction Materials*, vol. 19, art. no. e02470, 2023, doi: 10.1016/j.cscm.2023.e02470.

[6] P. Dybeł and M. Kucharska, "Effect of bottom-up placing on bond properties of high-performance self-compacting concrete", *Construction and Building Materials*, vol. 243, art. no. 118182, 2020, doi: 10.1016/j.conbuildmat.2020.118182.

[7] M. Kucharska and P. Dybeł, "Influence of casting direction on bond to steel reinforcing bars in self-compacting concrete", *Builder*, vol. 1, pp. 65–67, 2019 (in Polish).

[8] M. Kucharska and P. Dybeł, "Effect of placing self-compacting concrete bottom up on the quality of bond conditions", *Materials*, vol. 13, no. 10, art. no. 2346, 2020, doi: 10.3390/ma13102346.

[9] EN 1992-1-1:2024-05 Design of concrete structures, Part 1–1: General rules and rules for buildings, bridges and civil engineering structures. European Committee for Standardization, 2024.

[10] P. Dybeł, "Effect of bottom-up placing of self-compacting concrete on microstructure of rebar-concrete interface", *Construction and Building Materials*, vol. 299, art. no. 124359, 2021, doi: 10.1016/j.conbuildmat.2021.124359.

[11] P. Dybeł and M. Kucharska, "X-ray CT investigation of bond mechanism in reinforced SCC elements of different placement technology", *Materials*, vol. 14, no. 21, art. no. 6236, 2021, doi: 10.3390/ma14216236.

[12] EN 197-1 Cement – Part 1: Composition, specifications and conformity criteria for common cements. European Committee for Standarization, 2012.

[13] EN 12620:2010 Aggregates for concrete. European Committee for Standarization, 2010.

[14] EN 10080 Steel for the Reinforcement of Concrete. European Committee for Standarization, 2007.

[15] EN 13670 The execution of concrete structures. European Committee for Standardization, 2010.

[16] EN 12390-3 Testing hardened concrete. Compressive strength of test specimens. European Committee for Standardization, 2009.

[17] EN 12390-6 Testing hardened concrete. Tensile splitting strength of test specimens. European Committee for Standardization, 2009.

[18] RILEM TC, *RILEM Recommendations for the Testing and Use of Construction Materials, RC 6 Bond Test for Reinforcement Steel. Pull-Out Test, 1983*. E&FN SPON, 1994.

[19] fib Fédération internationale du béton, *Bond of Reinforcement in Concrete: State-of-the-art report*. Lausanne, Switzerland: International Federation for Structural Concrete, 2000.

[20] S.D. Hwang and K.H. Khayat, "Comparison of in situ properties of wall elements cast using self-consolidating concrete", *Materials and Structures*, vol. 45, no. 1–2, pp. 123–141, 2012, doi: 10.1617/s11527-011-9755-4.

[21] K.H. Khayat, K. Manai, and A. Trudel, "In situ mechanical properties of wall elements cast using self-consolidating concrete", *ACI Materials Journal*, vol. 94, no. 6, pp. 492–500, 1997.

[22] K.H. Khayat, E.K. Attiogbe, and H.T. See, "Effect of Admixture Combination on Top-Bar Effect of Highly Flowable and Self-Consolidating Concrete Mixtures", *ACI Symposium Publication*, vol. 247, pp. 33–41, 2007.

[23] P. Desnerck, "Compressive, bond and shear behaviour of powder-type self-compacting concrete", PhD thesis, Ghent University, Belgium, 2011.

[24] A. Castel, T. Vidal, K. Viriyametanont, and R. François, "Effect of reinforcing bar orientation and location on bond with self- consolidating concrete", *ACI Structural Journal*, vol. 103, no. 4, pp. 559–567, 2006, doi: 10.14359/16432.

Podawanie mieszanki samozagęszczalnej od dołu jako czynnik sprzyjający poprawie przyczepności stal-beton

Słowa kluczowe: betony nowej generacji, betonowanie od dołu, beton samozagęszczalny, czynniki technologiczne, efekt górnego pręta, przyczepność

Streszczenie:

Celem niniejszego artykułu była ocena wpływu technologii podawania mieszanki samozagęszczalnej (SCC) na przyczepność między stalą zbrojeniową a betonem samozagęszczalnym w pełnowymiarowych elementach ściennych. Analizie poddano dwa warianty technologiczne: tradycyjne podawanie mieszanki od góry oraz alternatywne podawanie od dołu. W ramach programu badawczego wykonano elementy ścienne o wymiarach 2240 × 1600 × 160 mm, a następnie przeprowadzono badania wyrywania prętów zbrojeniowych, wytrzymałości na ściskanie, rozciąganie przy rozłupywaniu oraz tomografię komputerową skoncentrowaną na otulinie prętów. Wyniki wykazały, że zastosowanie technologii podawania mieszanki od dołu prowadzi do istotnego wzrostu granicznych naprężeń przyczepności – średnio o 10% w porównaniu z metodą tradycyjną, ale również sztywności przyczepności. Zjawisko to przypisano poprawionej jakości otuliny betonowej, wynikającej z efektywniejszego odpowietrzenia mieszanki podczas betonowania, co ogranicza powstawanie pustek powietrznych w strefie kontaktu stal-beton. Ponadto, zastosowanie metody podawania od dołu przyczynia się do bardziej równomiernego rozkładu naprężeń przyczepności wzdłuż wysokości elementu, co skutecznie redukuje efekt górnego pręta, często obserwowany w przypadku elementów wykonywanych w technologii tradycyjnej. Obrazowanie tomograficzne potwierdziło zmniejszoną obecność pustek powietrznych spowodowanych osiadaniem mieszanki i zjawiskiem bleedingu w otulinie betonowej, co stanowi dodatkowe potwierdzenie wyższej jednorodności i jakości materiału. Uzyskane rezultaty wskazują, że technologia podawania mieszanek samozagęszczalnych od dołu stanowi obiecujące rozwiązanie w kontekście poprawy trwałości konstrukcji żelbetowych, w szczególności w konstrukcjach, w których kluczowe znaczenie mają jakość i jednorodność przyczepności pomiędzy stalą zbrojeniową a betonem.

Received: 2025-09-02, Revised: 2025-09-16