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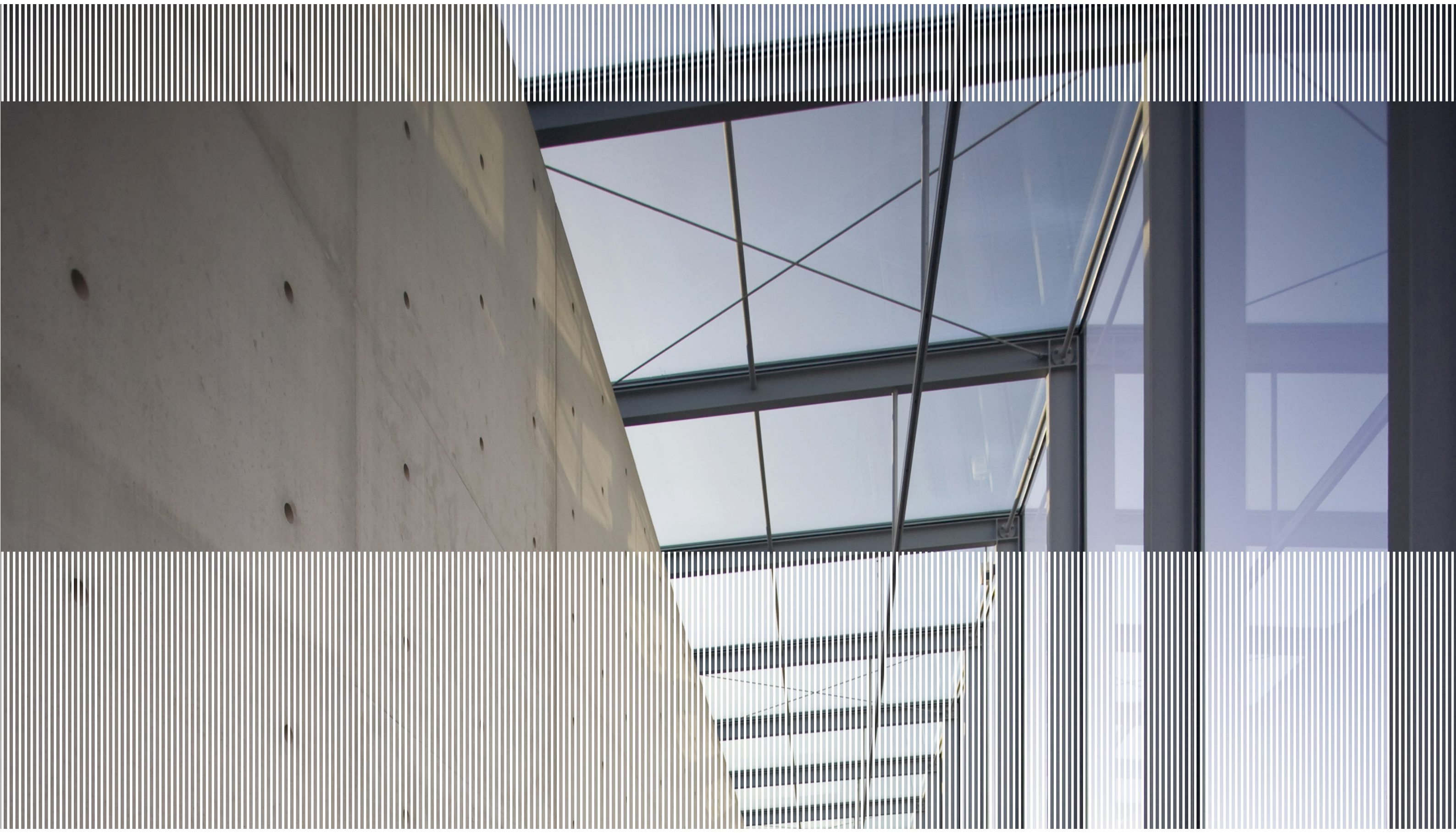
COIN Project report 59 – 2015



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FA: Competitive constructions

SP 2.1 Robust and highly flowable concrete with controlled surface quality

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Preface

This study has been carried out within COIN - Concrete Innovation Centre - one of presently 14 Centres for Research based Innovation (CRI), which is an initiative by the Research Council of Norway. The main objective for the CRIs is to enhance the capability of the business sector to innovate by focusing on long-term research based on forging close alliances between research-intensive enterprises and prominent research groups.

The vision of COIN is creation of more attractive concrete buildings and constructions. Attractiveness implies aesthetics, functionality, sustainability, energy efficiency, indoor climate, industrialized construction, improved work environment, and cost efficiency during the whole service life. The primary goal is to fulfil this vision by bringing the development a major leap forward by more fundamental understanding of the mechanisms in order to develop advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.

The corporate partners are leading multinational companies in the cement and building industry and the aim of COIN is to increase their value creation and strengthen their research activities in Norway. Our over-all ambition is to establish COIN as the display window for concrete innovation in Europe.

About 25 researchers from SINTEF (host), the Norwegian University of Science and Technology - NTNU (research partner) and industry partners, 15 - 20 PhD-students, 5 - 10 MSc-students every year and a number of international guest researchers, work on presently eight projects in three focus areas:

- Environmentally friendly concrete
- Economically competitive construction
- Aesthetic and technical performance

COIN has presently a budget of NOK 200 mill over 8 years (from 2007), and is financed by the Research Council of Norway (approx. 40 %), industrial partners (approx. 45 %) and by SINTEF Building and Infrastructure and NTNU (in all approx. 15 %).

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Tor Arne Hammer
Centre Manager

Summary

Many of the suggested methods for testing of SCC stability are quite demanding in execution and therefore seldom used in field. Furthermore, questions have been raised about how well they represent the stability problems in situ. The aim of the present investigation was therefore to find a method to assess stability of SCC which is practical, reliable and representative for in situ stability problems. This was done by a large scale test where the stability assessed according to four selected methods was compared with the stability assessed in low wall elements (10 m long) where the SCC was cast from one end, by measuring the distribution of the coarse aggregate content.

Two mixes of the same concrete were tested in order to see the comparison for both stable and unstable concretes. The one was known to give sufficient stability for wall casting, and the other one added more water reducing admixture to give rather poor stability. The results showed a good agreement between three of the methods and between these methods and the stability assessed by measuring the coarse aggregate distribution in the walls. One of these methods is a simple visual based assessment of the residue after the slump flow test.

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1 Introduction

Previous COIN-work on stability of SCC, reported in /1/, concluded with questioning the ability of stability test methods to mirror the stability problems in situ. The question is attempted answered in the investigation reported here, with the aim to find a method to assess stability of SCC which is practical, reliable and representative for in situ stability problems. Stability is considered here as the resistance to segregation of coarse aggregate, which is experienced to be a far more important stability problem than bleeding of such concretes.

The investigation started with setting up a number of requirements for the method, such as dynamic action and easy execution. It ended up in four recommended methods, as discussed and described in APPENDIX 1. The methods were then tested in the lab to gain experience and as basis for necessary adjustments, see APPENDIX 2.

Then, a large scale test was performed in order to compare the stability assessed according to the four methods with the stability assessed in low wall elements (10 m long) where the SCC was cast from one end, by measuring the distribution of the coarse aggregate content. Two concretes were tested; one known to give sufficient stability for wall casting, and one with expected rather poor stability, in order to see the comparison for both stable and unstable concretes.

The tests methods used were (see APPENDIX 2):
- Visual segregation, VSI^b
- Rheological Segregation, RSI
- Settlement Pipe Segregation Test, SPSI
- T-Box – dynamic segregation index, PDI, and dynamic segregation volumetric index, VI

2 Execution

2.1 Concretes

Two concretes were tested, delivered by UNICON in a truck mixer. The first one was similar to the SCC used by Skanska for the walls of "Stjørdal Cultural Centre". The other one was similar to the first one, but added more water reducing admixture (WRA) on site to make it fairly unstable. The recipes, along with the slump flow and t_{500}, are given in Table 1.

Table 1 Recipe and consistency of the UNICON concrete

Materials	Mix A	Mix B
Cement, CEM II/A-V 42.5R ("Norcem STDFA")	364	364
Silica fume ("Elkem Micro silica U 940 ")	19	19
Water	189	189
WRA ("Glenium SKY 601")	5.2	5.8
Sand/gravel, 0 – 10 mm	1162	1162
Crushed stone, 8 – 16 mm	637	637
w/c	0.53	0.53
Slump flow	700 mm	740 mm
t_{500}	0.8 sec.	<0.4 sec.

2.2 Wall formwork

The tests were performed at Contiga's precast factory in Stjørdal outside Trondheim. The wall formwork had dimension l/h/w = 10/0.6/0.2 m, and was made of Plywood. No reinforcement was used. The stability was assessed by measuring the coarse aggregate content, particles > 5 mm, in both ends of the wall and in two in between positions, as well as on top and bottom in all positions (i.e. a total of eight points in each wall), see Figure 1 and 3. To enable careful sampling in the bounded positions without interference from concrete outside the positions, two metal plates were pressed down in pre-cut notches in the Plywood with a mutual spacing of 0.2 m, see Figure 1. To make action of pressing down the plates as easy as possible, the cuts were filled with silicone grease prior to casting, to avoid blocking by sand particles.

Figure 1 The wall elements with metal plates bounding the area for sampling.

2.3 Execution

Prior to the tests, the slump flow was adjusted on site by adding WRA in the truck until the target of 700 and 740, respectively, was achieved. Casting of the walls and testing with the four methods were done simultaneously, during approximately 60 minutes. The walls were cast directly from the truck gutter, see Figure 2. The filling took 5-6 minutes in both cases. Within half an hour after completed casting, the metal plates were pressed down and sampling was done immediately after. Each sample of approx. 5 litres, were taken out with a shovel and filled in a bucket with known volume. The sample was weighed, then placed on a 5 mm sieve and flushed with water until the coarse aggregate appeared clean. At last, the aggregate on the sieve was packed in bags to be transported to the lab for drying and weighing.

Figure 2 Casting of wall elements from truck gutter

The samples to be used in the four lab tests were taken from wheelbarrows filled directly from the truck gutter. The wheelbarrows were handled carefully to prevent segregation, and the concrete was remixed by hand before starting the lab tests. This was done to ensure homogenous and representative concrete. The procedure of each test is given in APPENDIX 1.

3 Results

All measurements are tabulated in APPENDIX 3.

3.1 Wall test

The surface slope over the 10 m were 0.11 m for Mix A and somewhat less for Mix B, 0.07 m, as expected because of higher slump flow, see Figure 3.

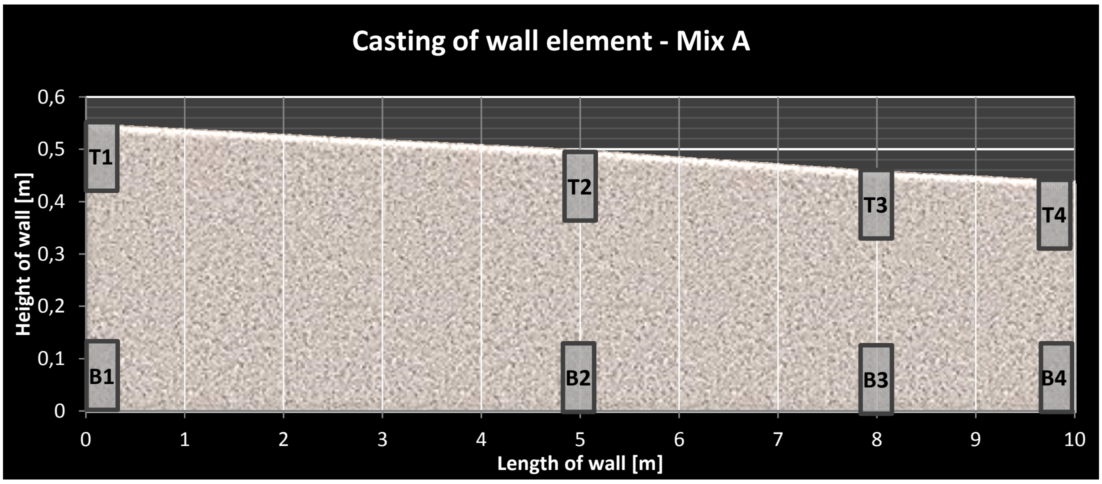

Figure 3 Slope of the concrete surfaces and locations for sampling (T1-T4, B1-B4)

The results are presented, in Figure 4, as the measured mass of aggregate > 5 mm in the selected locations shown in Figure 3, when dried at 105 °C to constant weight and given as kg/m^3 of concrete. It is compared with the corresponding mix design aggregate content of 819 kg/m^3.

The difference between the concretes is obvious: The coarse aggregate (stone) distribution in Mix A is quite uniform, both over the length and height, while it varies considerably in Mix B. both over the length and height. It seems that the stone followed up to 8 m (the sum of bottom and top is fairly constant), but that the vertical segregation started already at filling. In fact, the top section at the flow end of the beam did hardly contained stone. Hence, Mix A can be judged to exhibit satisfactory stability for this job, and Mix B certainly not.

Apparently, the total coarse aggregate content (bottom plus top) is lowest at the filling end highest at the flow end. Spangenberg et al [2] also found that the total stone concentration at the filling was lower than in the middle section of a similar test wall. A higher stone content especially at the top for Mix A, corresponds to the observation that stones tend to be pushed upward when the concrete met the end wall.

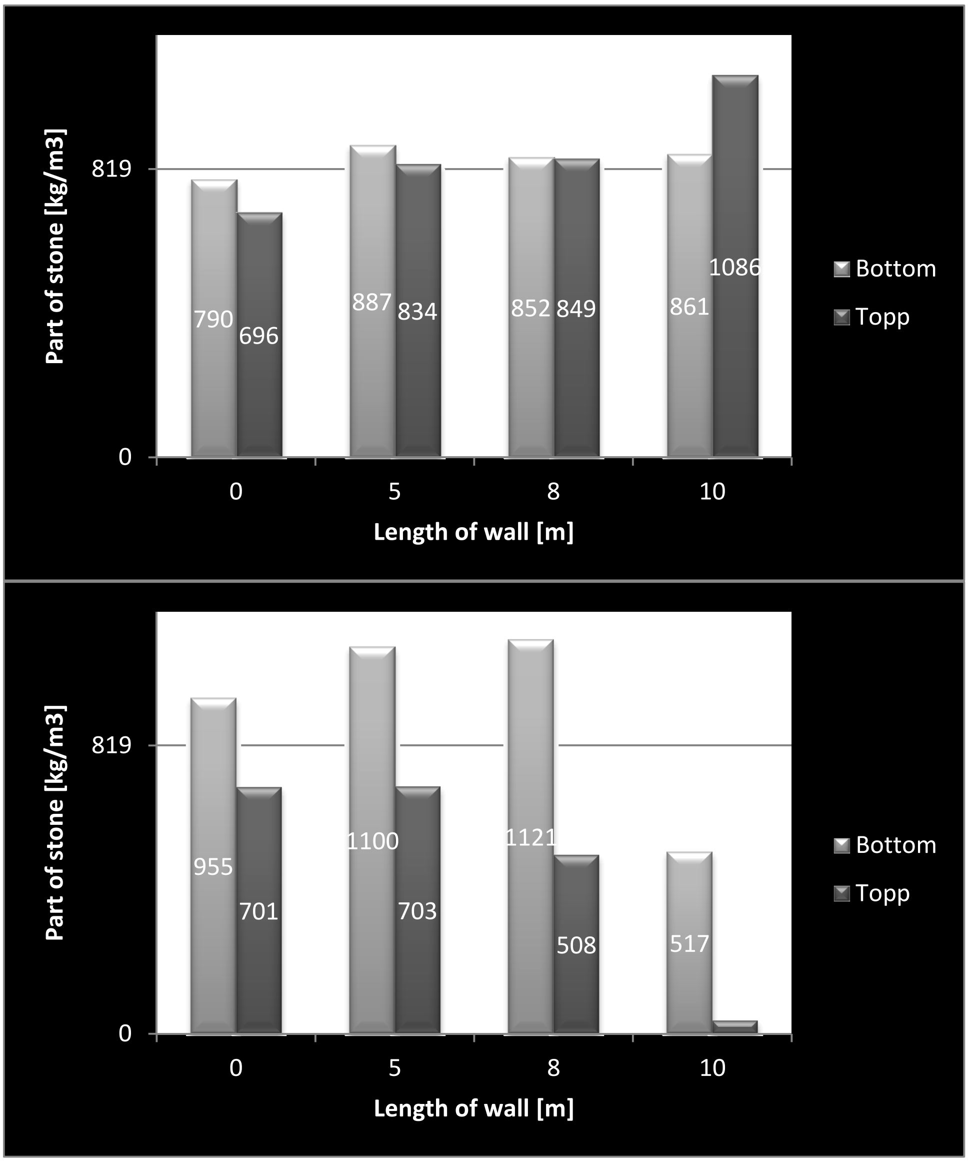

Figure 4 Coarse aggregate content in the selected locations. The coarse aggregate content taken from the mix design is 819 kg/m^3

3.2 Stability tests

There is a very good agreement between the methods in that all results from testing Mix A indicate acceptable stability, see Table 2, and thus in accordance with the result from the wall test. And the indices are rather close to the limits of acceptance, except for the VI from the T-Box. This makes sense since a rather little increase of WRA (5.2 to 5.8 kg) caused a quite unstable concrete (Mix B). The VI is far below the acceptance criteria, and thus, indicates very good stability. Note that this disagreement can lay in the restriction of the T-Box test as discussed below.

Also, results from testing of Mix B were in accordance with the beam test; not acceptable, except for the T-Box test results. The T-Box results were irrational: PDI (penetration indicator) of minus 6 mm and VI (content of coarse aggregate indicator) lower than that for Mix A. It lays probably in the restriction of the T-Box test, saying: "Do not perform this test on self-consolidating concrete which does not show sufficient static stability". We did not measure static stability as such, but the PDI includes an initial measurement of penetration before tilting. It showed 9.5 mm penetration, which must be considered to be quite high, and thus, indicates poor static stability (concrete A showed 2 mm, only).

Table 2 Results and limits for acceptable stability (green and red indicate stable and instable concrete, respectively, according to the test methods)

Concrete	VSI[b]	RSI	SPSI	T-Box	
				PDI	VI
	≤ 0.6	≤ 0.5	≥ 0.88*	≤ 6 mm	≤ 25 %
A, SU=700, t_{500} = 0.8	0.55	0.5	0.88	4.5 mm	4.7 %
B, SU=740, t_{500} = 0.4	0.75	0.9	0.68	**-6 mm**	1.4 %

** According to the original Settlement Column Test (APPENDIX 1)*

Similar comparisons have been performed earlier. The EU GROWTH-project "Testing-SCC" [3], concluded that the "Sieve Segregation Test" gave the best correlation with stability assessed in situ (but yet not consistent), followed by the "Penetration Test" and "Settlement Column Segregation test" (from which our SPSI-test is modified). We considered the two others to be too execution demanding to fit our aim. VSI and RSI were not a part of the "Testing-SCC".

4 Final assessment - conclusion

The present reference concrete is judged to be quite sensitive with respect to stability based on the facts a) that it has a rather high SU and a low viscosity (as indicated by the low t_{500} of 0.8 sec.) as a result of a high water-powder ratio, and b) that only little extra addition of WRA made it quite unstable. Bearing this in mind, it is encouraging that three of the stability test methods showed good agreement between them, and more important, with the results from the wall tests, both when the stable and the unstable concrete is considered. The experimental results confirm that these methods may be suitable for qualification, declaration and acceptance control purposes, at least for concretes fairly similar to the present ones, i.e. most Norwegian SCCs for buildings. Similar comparison should be done with concretes having higher viscosity, either by use of more/other fines or viscosity modifying admixtures. The latter may be the most interesting one as it is often used to repair unstable concrete on site.

Given that the three methods; **Visual Segregation Index (VSI), Rheological Segregation Index (RSI)** and **Settlement Pipe Segregation Index (SPSI)**, predict the stability of SCC on just as well, the questions about easy handling, time consumption and robustness remain to answer. Note that taking a representative and homogenous sample from the truck or mixer is of outmost importance for all tests (a general challenge not only for stability measurements), especially if the concrete is unstable or on the limit of being accepted as stable. Assuming that this is taken care of, the following evaluation is done:

The **VSI-test** is obviously the easiest and fastest one, also because slump flow is measured in most cases anyway. The main weakness is a possible person dependency, surely related to the execution of the slump flow test itself but mainly to the evaluation of the stability, i.e. grading (0 to 1) according to the given description. Allowing a number of people to perform the evaluation simultaneously on the same slump flow residue, would answer this question, and perhaps form a basis for a possible modification of the description.

The **RSI-test** is relatively easy and fast, but data has to be processed in a separate computer. We assume that the device can be further developed with data processing integrated. The person dependency is considered to be unimportant.

The **SPSI-test** is the slowest and less easy one of the three. It includes also flushing, drying and weighing of the coarse aggregates. Hence, it takes quite much time to get the results. The test might be person dependent; at least it should be checked. Its strength is that the results are fairly directly to the point; the distribution of coarse aggregate. Hence, it seems suited for e.g. declaration procedures.

The fourth test, T-Box test, seems to be too sensitive to allow reliable evaluation of concretes similar to the ones tested here. It is moreover rather demanding to operate, especially if the second option of the procedure is chosen, in that it includes flushing, drying and weighing of the coarse aggregates.

5 References

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APPENDIX 1

In-situ stability test methods for SCC

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1 Introduction

There is a lack of a sound, reliable and practical test method for determination of stability of SCC that represents the stability problem in-situ. One challenge is that there exists little information about the correlation between existing methods and the stability problem in-situ. One aim of the work in COIN P2.1 is to recommend such a method, based on investigation of the homogeneity of SCC cast in-situ and stability characterisation according to selected test methods. The present memo discusses relevant methods as basis to select the methods to be used in this investigation.

One challenge is the strong dynamic action that challenges the stability in-situ. Some of the known methods are dynamic and some are static. It is maybe possible to find a correlation between dynamic and static stability test methods for similar concretes, but probably not a universal correlation. For instance, since the thixotropic behaviour of some SCCs will dominate in static tests while not in dynamic test. Hence, a method should reflect a dynamic situation. Accordingly, only dynamic test methods are discussed here. Furthermore, as segregation of coarse aggregate is by far the most important stability problem in-situ, matrix segregation tests are excluded here.

A method describes how the dynamic action is applied and the responds which includes how the segregation is measured. The dynamic action can be applied by the force of a mixer or rheometer, flow or by jolting. The responds in the fresh state can be measured by:

- visual observation,
- rheological measures,

- sieve test to find the amount of coarse aggregate,
- penetration to find the thickness of segregated layer
- electrical conductivity

2 Requirements for the method

2.1 Dynamic action

The in-situ dynamic action is flow resulting from gravity. The responds, i.e. how the segregation appears depends on the geometry of the form, e.g. if it is a slab or wall, and the casting procedure. Segregation of coarse aggregate is the dominating result, and therefore should be reflected in the test method. It has been shown that a multilayer structure may appear when casting a section of relatively low height; settled aggregate particles at the bottom, a sheared zone with little aggregate particles and on top a rather unsegregated plug flow zone. Casting of higher sections; typically a wall, may give more complex segregation pictures since the flow then in parts may deviate from the horizontal direction.

In general, the action is considered to be rather hard, which should be reflected in the method.

2.2 Execution and measuring

- Rapid
- Practical
- Good repeatability and robust,
  meaning minimal influence of variation in execution. Note that taking a representative sample from the truck is a general challenge, not only for stability measurements, especially if the concrete is unstable or on the limit of being accepted as stable.

In addition it is of course important that the price of the equipment is acceptable.

3 Existing methods

3.1 Visual segregation index, SINTEF-method

VSI [1] is measured on fresh concrete within the mixer (VSI^m) and on the flow board (VSI^b) after determination of slump flow. Table shows the VSI rating within the mixer.
Table shows correspondingly the VSI rating on the flow board. A castable concrete should have a VSI^m between 0 and 0.5 and a VSI^f between 0 and 0.6.

Table 1: VSI^m measured directly after end of mixing in the concrete mixer

0 / 0.1	Stable and homogenous concrete
0.2 / 0.3	Creamy surface and formation of small air bubbles, but still stable.
0.4 / 0.5	Incipient separation, lots of small air bubbles/pores, tendency of sludge layer, formation of black film on the surface.
0.6 / 0.7	Clear signs of separation, strong ”boiling”, sludge layer, black film, coarse aggregates sinking towards the bottom of the mixer.
0.8 / 0.9	Strong boiling, clear water layer, 5-20 mm sludge layer, aggregates lying at the bottom of the mixer.
1	Complete separation.

Table 2: VSI[b] measured on concrete on the flow table directly after a slump flow measurement

0 / 0.1	Stable and homogenous concrete. Aggregates and paste flow towards the rim of the sample.
0.2 / 0.3	Stable and homogeneous concrete that flows well, but has become a shiny surface with possible black spots (usually unburned coal residue liberated from the fly ash when the hollow spheres are crushed upon grinding).
0.4 / 0.5	Has additionally a hint of a paste rim at the outer edge of the spread, but the aggregates follow the flow towards the edge. Still stable.
0.6 / 0.7	Clear rim of paste at the outer edge of the spread. Coarse aggregates tend not to flow towards the edge of the spread (are left in the middle of the spread).
0.8 / 0.9	Additional separation of water/paste at the outer rim of the spread.
1	Complete separation

There exist visual methods also based on image analyses of hardened concrete. It is however not relevant hence the given requirement (chapter 2).

Evaluation:
The VSI[m] is not relevant since it based on how the concrete appears immediately after mixing in a lab pan mixer.

The VSI[f] satisfies the requirement for easy and rapid testing. It follows the same requirements for sampling as the slumpflow test, indicating equal repeatability and robustness. See however the note in section 2.2. Also, the method gives additional information in that it allows evaluation of matrix/bleed water segregation (by observation of the rim on the flow table). It is questionable if the dynamic action is sufficiently strong to reflect the in-situ action. The method is nevertheless considered to be qualified for the test program.

3.2 Rheological Segregation Index (RSI)

The RSI [3] is determined using a 4SCC rheometer produced by ConTec with a special rotor which simulates a dynamic separation process by pushing the coarser aggregates aside. After 60 s the rheological parameters G and H of the resulting separated slurry are measured. G relates to the yield stress and H to the viscosity. The RSI value has been calibrated to the VSI[m] and has hence the same limits for stability.

Evalution:
The practical part; filling and testing, is easy and fast. The dynamic action is relatively high, and the method seems to have a limitation that can be used to exclude unstable SCC: It segregates unstable SCC so much that RSI values become unreasonable. The current version of the method requires a special instrument and computer to calculate RSI, which is a drawback considering cost, time and execution. Jon Wallevik says that a "compact" version with a "go-button" and a small display giving the RSI directly may be built for practical use. Then, it is a matter of price if the potential user will purchase it. Nevertheless, the method is considered to have the potential to become good, and therefore suggested to be a part of the program.

3.3 Column test

See APPENDIX 1. The test involves samples of concrete being taken from the top part and bottom part of a column shaped apparatus via doors after a controlled jolting cycle and standard settlement period. Segregation resistance is expressed as the ratio between coarse aggregate mass in the top part and coarse aggregate mass in the bottom part. A lower ratio indicates more coarse aggregate in the bottom layer, therefore an increased liability to segregation.

Evaluation:
The method has been used some 12 years ago in Norway, with the following experience (2):

Tabell 10 viser hvordan University of Paisley foreslår å kategorisere separasjonstendensen i SKB på basis av SCT-indeksen. De fleste av betongene som er prøvd her faller innenfor kategorien ”Betydelig separasjon”, til tross for at betongenes flyteevne 30 minutter etter vanntilsetning må karakteriseres som moderat. SCT-metoden er sannsynligvis utviklet for, og verifisert med betonger med lavere v/p forhold enn de som er prøvd her. Dette har gitt høyere viskositet i betongene, lavere separasjonshastighet, og dermed høyere SCT-indeks.

Tabell 10. Leverandørens anbefalte kategorisering av separasjonstendens på basis av SCT-indeksen.

SCT-indeks	Nivå av separasjon
> 0,95	Ingen separasjon
0,95 - 0,88	Noe separasjon
0,87 - 0,72	Betydelig separasjon
< 0,72	Kritisk separasjon

Figur 19 viser sammenhengen mellom plastisk viskositet (målt 10 minutter etter vanntilsetning) og SCT-indeksen (målt etter 30 minutter). Figuren viser en viss tendens til økende stabilitet ved økende viskositet, men sammenhengen er ikke så klar som man kunne forvente. Betongene med Mapefluid RN15 og ScanFlux AD18 kombinert med Standardsement gir en lav SCT-indeks til tross for at disse betongene har høyest plastisk viskositet.

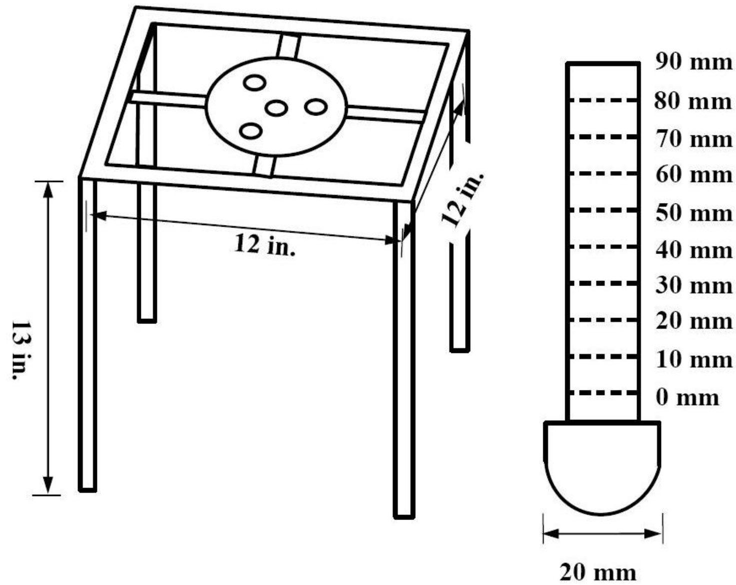
Prøvingsomgfanget er generelt for lite til vurdere SCT som prøvemetode. De resultatene som er vist her indikerer imidlertid at metoden kan provosere fram større separasjonstendens enn det den visuelle vurderingen skulle tilsi. Dette gjelder sannsynligvis i særlig grad betonger med høyt vann/pulver-forhold, og dermed lav viskositet. Leverandørens anbefalte kategorisering av resultatene stemmer dermed ikke overens med det som etterhvert er akseptert som vanlige brukskriterier for slike betonger. Metoden er også meget arbeidskrevende, og er i beste fall aktuell i større laboratorieundersøkelser som spesielt fokuserer på betongens stabilitet.

It was also a part of the European project "Testing-SCC". In the summary report from "WP3.3 Test for resistance to segregation" [3], the conclusion sais: "Settlement column test seems to be less able to detect poor resistance to segregation of fresh concrete" (compared to the other methods in the investigation).

Sonebi et al [4] tested the method against the distribution of coarse aggregate in hardened concrete (cut surfaces) which was given the same action in the fresh state, and found a good relationship. It indicates that the method reflects the truth given the action. But it does not tell if the given action reflects the in-situ action.

The principle is simple; filling a column and jolt it, but the measurement rather demanding. It would be worth trying to measure the penetration resistance from the top instead, for instance according to El-Chabib and Nehdi [5], which is a multiple-probe test incorporating four solid penetration probes (see sketch below), or by electrical conductivity [6]. The latter requires probably quite much development work to make it easy and practical.

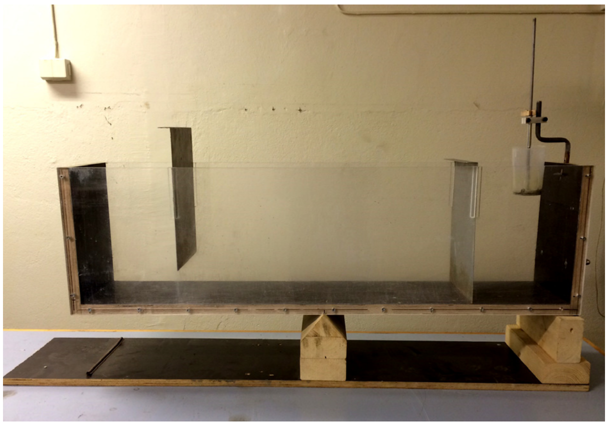
It is suggested to include the jolting column principle in the test program.

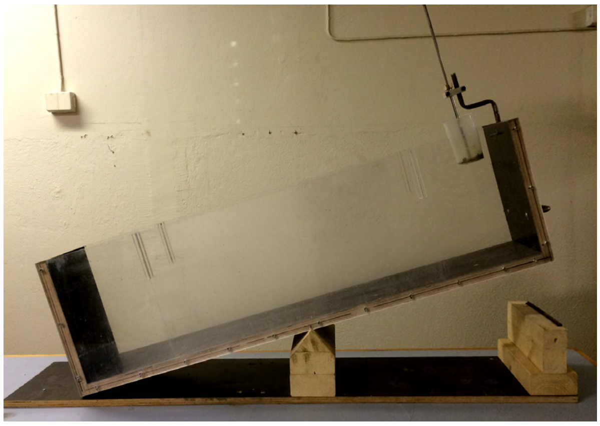


3.4 Standard Test Method for Dynamic Segregation of Self-Consolidating Concrete by T-Box

The method is a coming ASTM-standard, and described by Esmaeilkhanian et co [7]. A sample of freshly-mixed self-consolidating concrete is placed in a rectangular channel without tamping or vibration. The channel is tilted numerous times through cyclic motions. By means of a penetrometer, the penetration depth is measured on the extremity that tilts upwards before and after the tilting cycles. The difference between the initial and the final penetration depth is an indicator of dynamic segregation.

A comparison of the coarse aggregate content in tilt-up and tilt-down sections at the end of the T-Box test can also be done to provide an indication of dynamic segregation.





Evaluation: The ASTM standard describes that "the test method provides users with a laboratory procedure to determine the potential dynamic segregation of self-consolidating concrete". It implies that it is not designed for building site measurements. However, the principle seems promising and simplifications to meet in-situ measurement requirements should be considered.

4 Summary

The methods considered relevant for in-situ measurement of SCC stability are listed below:

Method	Vessel		Action	Measure		Time	Practi-cability
	Standard	Modific.		Standard	Modific.		
VSI[b]	Slump-cone	no	"Bad"?, gentle flow	Visual		Very rapid	Good
RSI	10 l bucket	no	Good, beater	Rhemoetry	Simplifi-cation	Slow, rapid when mod	Bad, good when mod.
Column	100/150/520 mm column	150/400 mm column?	Good, jolting	Sieving	Pene-tration?	Very slow, less slow when mod	Bad, but accept. when mod?
T-Box	200/300/1000 mm box	?	Good, jolting	Penetration and sieving	More robust?	Very slow	Bad, but potential to become accept.?

5 References

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2. Smeplass, S. and Johansen, K.: Utvikling og dokumentasjon av SKG, DP1 Reologi, Effekt av ulike copolymerer på støpelighet og tidlig fasthetsutvikling. Norcem-rapport 9D4/R02064, 2002
3. Cussigh, F. and Bonnard, V.: Testing-SCC, Summary report of WP 3.3 Tests for resistance to segregation. GTM Construction, report DITC/VBo/PHa/2888/04, Nanterre, 2004
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5. El-Chabib, H., and M. Nehdi. 2006. Effect of mixture design parameters on segregation of self-consolidating concrete. ACI Materials Journal 103, no. 5:374-383.
6. Mesbah, H.A., Yahia A. and Khayat K.H.: Electrical conductivity method to assess static stability of self-consolidating concrete. Cement and Concrete Research 41 (2011).
7. Esmaeilkhanian, B., Feys, D., Khayat, K.H., and Yahia, A., New Test Method to Evaluate Dynamic Stability of Self-Consolidating Concrete, ACI Materials Journal, 111 (3), May 2014, pp. 299-308.

Method for the Determination of Coarse Aggregate Segregation Resistance of Flowable Fresh Concrete by Means of the Settlement Column Test

Scope:

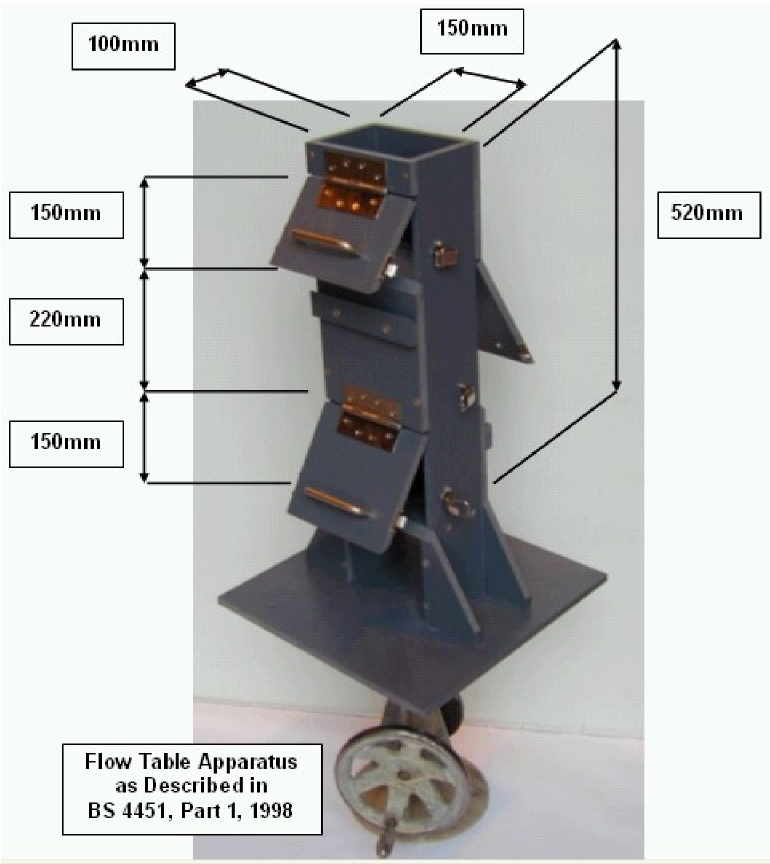
This document details the method for determination of the resistance to coarse aggregate segregation of flowable fresh concrete by means of the Settlement Column Test.

Apparatus:

- Settlement Column apparatus – shown in Figure 1.
- Flow Table apparatus – shown in Figure 2.
- Two small G-clamps to secure Settlement Column apparatus to Flow Table apparatus.
- Sample bucket with a capacity of at least 8 litres.
- Scoop.
- Timepiece.
- Two small collection trays with a capacity of 1.8 litres.
- Large collection tray with a capacity of at least 3.3 litres.
- Large diameter 5mm sieve.
- Water supply.
- Oven (optional).
- Balance.

Figure 1 - Settlement Column Dimensions.

1



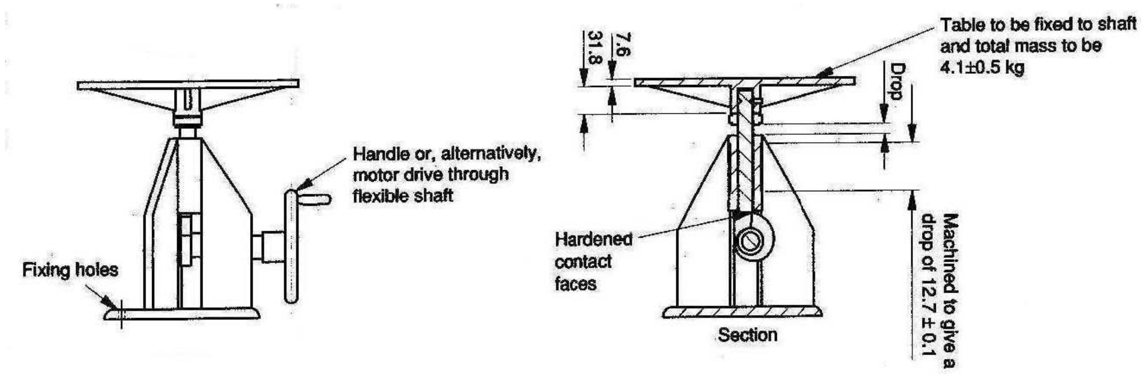


Figure 2 – Flow Table dimensions as described in BS 4551, Part 1, 1998.

Sampling:

After completion of the mixing process, the concrete should be covered with a non-absorbent material and allowed to stand static within the mixer for a period of 10 minutes. After this period has elapsed, the mixer should be re-started for a 10 second period. An 8 litre representative sample should then be taken from the mixer and placed into the sample bucket and mixed by hand using the scoop. This procedure should be followed each time the test is conducted to ensure consistency.

Procedure:

1. The Settlement Column apparatus should be secured to the Flow Table apparatus by means of the two small G-Clamps.

2. The interiors of the Settlement Column apparatus and the 1.8 litre collection trays should be dampened but free from excess moisture. The hinged doors of the apparatus should be secured in a closed position.

3. Immediately after the sampling procedure described above, the concrete should be poured from the sample bucket into the Settlement Column apparatus. When the apparatus has been completely filled with concrete, it should be allowed to stand static for a period of 1 minute. This procedure should be followed each time the test is conducted to ensure consistency.

4. When this period has elapsed, the apparatus should be jolted 20 times within a 1-minute period via the turn handle of the Flow Table apparatus.

5. After jolting, the apparatus should be allowed to stand static for a settlement period of 5 minutes.

6. When this settlement period has elapsed, the top door of the apparatus should be opened and the top sample should be allowed to flow into the first small collection tray. If required, the flow of concrete from the column should be assisted by means of the scoop. Any excess concrete within the collection tray should be struck off by means of the scoop.

7. The middle door of the apparatus should be opened and the middle sample should be allowed to flow into the large collection tray. This sample should then be discarded.

8. The bottom door of the apparatus should be opened and the bottom sample should be allowed to flow into the second small collection tray.

9. The top sample should be placed into the 5 mm sieve and the mortar content should be completely washed out by means of the water supply so that only the coarse aggregate remains.

10. The sieve should be cleaned and the bottom sample should then be placed into the sieve and the mortar content should be completely washed out by means of the water supply so that only the coarse aggregate remains.

11. The coarse aggregate from both samples should be dried. It is preferable that the coarse aggregate samples are dried in an oven or by other artificial means in order that a result can be obtained in the minimum possible period of time. However if time is not an issue, then the samples may be allowed

to dry naturally. Natural drying will result in a higher moisture content being retained within the aggregate than oven drying, therefore it is important that whatever method is chosen, the top and bottom samples are dried in an identical manner for approximately the same period of time.

12. The coarse aggregate in the top sample should be placed onto the balance so that its mass can be determined and this should be recorded to the nearest 1 gram.

13. The coarse aggregate in the bottom sample should be placed onto the balance so that its mass can be determined and this should be recorded to the nearest 1 gram.

14. A segregation ratio should then be calculated from:

segregation ratio = mass of top sample / mass of bottom sample

15. The segregation ratio should then be expressed to two decimal places.

Interpretation of Results:

Once a result has been obtained, it should be checked against Table 1 shown below in order to determine the level of segregation present within the concrete tested.

Table 1 – Levels of segregation (Rooney, 2002).

Level of Segregation	Segregation Ratio
1. No Segregation	0.96 and above
2. Mild Segregation	0.95 – 0.88
3. Notable Segregation	0.87 – 0.72
4. Severe Segregation	0.71 and below

Repeatability and Reproducibility:

No full-scale repeatability or reproducibility experiments have been conducted into the Settlement Column test. However, some initial information has been gained from limited test programmes. For mixes deemed to have no segregation and mild segregation – in accordance with Table 1 – the following repeatability and reproducibility information is available (Table 2 & Table 3). Results are expressed as coefficient of variation values.

Table 2 – Repeatability and reproducibility data for concrete with no segregation).

No Segregation	
Repeatability	**Reproducibility**
Approx. 3.5%	Approx. 4%

Table 3 – Repeatability and reproducibility data for concrete with mild segregation.

Mild Segregation	
Repeatability	**Reproducibility**
Approx. 4%	Approx. 8%

APPENDIX 2

Stability test methods – Initial lab testing

	MEMO				
SINTEF sfi Centre for Research-based Innovation	MEMO CONCERNS **COIN P2.1 – Stable and Robust Highly Flowable Concrete** **In-situ stability test methods for SCC - Initial labtesting of the four chosen methods**	FOR YOUR ATTENTION	COMMENTS ARE INVITED	FOR YOUR INFORMATION	AS AGREED
	DISTRIBUTION COIN FA2.1 project group		X		

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PROJECT NO.	DATE	PERSON RESPONSIBLE / AUTHOR	NUMBER OF PAGES
3D0059.40/60	2013-08-20 Mod. 2015-01-05	Tor Arne Martius-Hammer	6

1 Introduction

Reference is made to the memo dated 2013-08-20, "COIN P2.1 – Stable and Robust Highly Flowable Concrete, In-situ stability test methods for SCC", that presents the background for the choice of and the description of the four stability test methods tested here:

- Visual segregation, VSI^m and VSI^b
- Rheological Segregation, RSI
- Settlement Pipe Segregation Test, SPI
  The test has been modified from the one described in the afore mentioned memo: The present column has a circle shaped cross section (150 mm in diameter) and not a rectangular one. The total column height is 450 mm, and the concrete volumes considered is the top 150 mm and the bottom 150 mm (the middle section is not used)
- T-Box - dynamic segregation index, PDI, and dynamic segregation volumetric index, VI

2 Settlement Pipe Segregation Test – "running in"

2.1 Test method

The description of the **Method for the Determination of Coarse Aggregate Segregation Resistance of Flowable Fresh Concrete by Means of the Settlement Pipe Segregation Test,** is shown below:

Apparatus:

- Settlement Pipe apparatus with Flow Table apparatus – shown in Figure 1
- Two wing nuts to secure Settlement Pipe apparatus to Flow Table apparatus
- G-clamps to secure the Flow Table apparatus to a table
- Sample bucket with a capacity of at least 8 litres
- Squeegee
- Timepiece
- Three collection trays with a capacity of minimum 2.7 litres
- Large diameter 5mm sieve
- Water supply
- Oven (optional)
- Balance

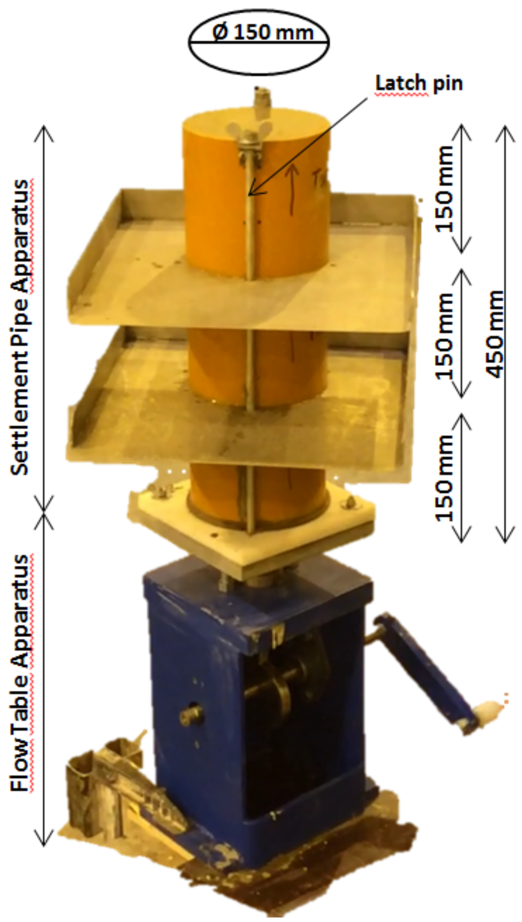


Figure 1: Settlement Pipe Dimensions

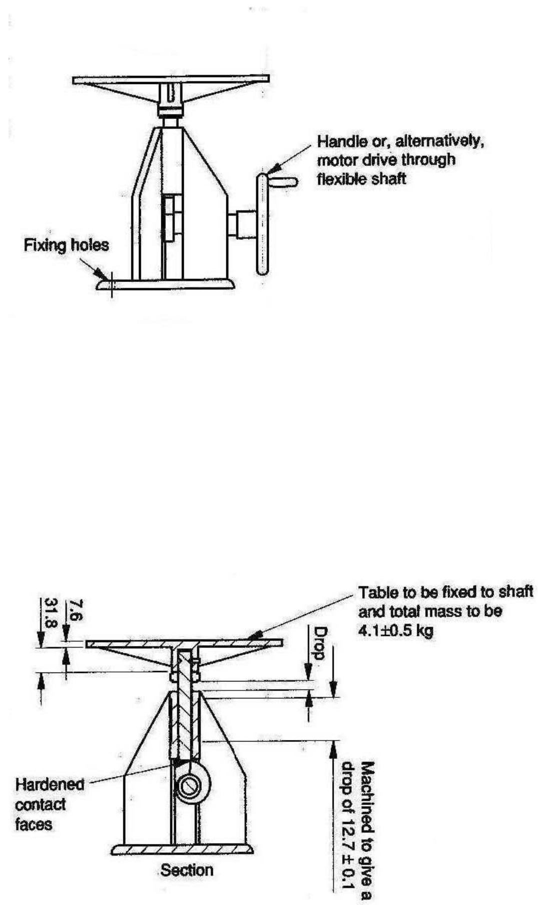


Figure 2: Principal drawing - Flow Table dimensions as described in BS 4551, Part 1, 1998

Sampling:

After completion of the mixing process, an 8 litre representative sample was taken from the mixer and placed into the sample bucket and mixed by hand using the scoop.

Procedure:

1. The Settlement Pipe apparatus was secured to the Flow Table apparatus by means of the two wing nuts. The Flow Table apparatus was secured to a table with G-clamps. The three Settlement Pipe cylinders should was secured with the long latch pin.

2. Immediately after the sampling procedure described above, the concrete was poured from the sample bucket into the Settlement Pipe apparatus. When the apparatus has been completely filled with concrete, it was allowed to stand static for a period of 1 minute.

3. When this period had elapsed, the apparatus was jolted 20 times within a 1-minute period via the turn handle of the Flow Table apparatus.

4. After jolting, the apparatus was allowed to stand static for a settlement period of 5 minutes.

5. When this settlement period had elapsed, the long latch pin was removed enabling to lift off the top cylinder. The concrete flown out on the tray below the cylinder was shoved to a sampling tray with the squeegee, see Figure 3.

6. The middle cylinder of the apparatus was lifted off and the middle sample was then discarded.

7. The bottom cylinder of the apparatus was loosened from the flow table apparatus by removing the two wing nuts. The bottom sample was then poured into another collection tray.

8. The top sample was placed into the 5 mm sieve and the mortar content was completely washed out by means of the water supply so that only the coarse aggregate (> 5 mm) remained. The same was done with the bottom sample after cleaning the sieve.

9. The coarse aggregate was then dried in an oven, and after that placed onto the balance to measure the mass to the nearest 1 gram.

10. The Settlement Pipe Segregation Index, SPSI was then calculated as:

    SPSI = mass of top sample / mass of bottom sample

    The result is expressed by two decimals.

Figure 3: Sampling from the Settlement Pipe Apparatus

2.2 Tests

Since the present set up was never used before, two test series on one concrete (one recipe) were conducted to gain experience and as basis for necessary adjustments. Each series included six tests on one concrete batch: Three consecutive tests, the first one staring 10 min after water addition, and then three consecutive tests, the first one staring 60 min after water addition. The duration between each consecutive test was approximately 10 minutes.

The concrete chosen (M60) is similar to one of those used in a previous stability test program in COIN [Martius-Hammer et al, 2012], characterised as "slightly unstable" (VSI^m and VSI^b of 0.75 and 0.55, respectively). In the present case VSI^m and VSI^b were 0.75 and 0.5, and 0.75 and 0.55, for series 1 and 2, respectively. Slumpflow was 700 and 680 mm, respectively, and t_{500} 1.9 s and 2.1 s, respectively.

The results (SPSI = ratio between weight of coarse aggregate (5 mm) in the top section and bottom section), are given in Fig 1.

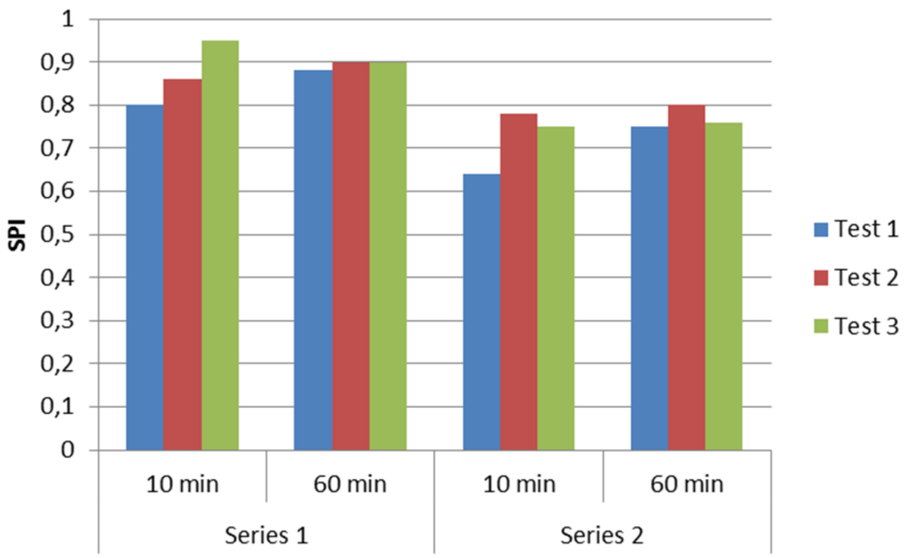


Fig 1. Results from the very first tests with the new Column Test

As can be seen, there is some variation in the results between the three consecutive tests. Since the concrete appears slightly unstable, there is a risk that the homogeneity of the various test samples taken from the mixer may vary, even if much effort like remixing before taking concrete out of the mixer and hand mixing by a ladle in the pitcher before pouring out, was done to prevent it. The fact that the variation of the 60 min tests was less, i.e. when the concrete appeared more stable (e.g. seen as average SPI lower at 60 min than at 10 min in both series), supports this assumption. Another reason for the variation could be some random spill of coarse aggregates when collecting the concrete from the top part of the column (contributing to a lower measured SPSI). This part of the procedure has been improved after these tests.

It is surprising that SPSI is so much lower in series 2 than in series 1, since SF, t_{500}, SP-content and VSI do not indicate any considerable difference in stability. We have not found any plausible reason for this. It certainly shows that more work should be done to find a reliable procedure.

3 T-Box – "running in"

Since we had no experience with the test, it was tried once before the full program with all four test methods. The concrete used was the intended "full scale test concrete" from UNICON, Stjørdal (materials were sent to us from the concrete plant). The recipe is given in Table 1. Slumpflow was 670 mm, t_{500} was 1.1 sec., and VSI^m and VSI^b were 0.55 and 0.2, respectively. PDI was 2 mm, indicating good stability (as VSI indicated). VI was not measured. The test appeared as rather easy to execute, but the penetration measurement requires special attention and precision.

4 Testing with the four methods in parallel

The "UNICON-concrete" (Table 1) was used and the tests were carried out three times, i.e. on three batches with presumed different stability by adjusting the superplasticiser amount to give SU of 680 mm (reference), 725 mm and 750 mm, respectively. The reference is known to exhibit sufficient stability for casting of walls (Stjørdal kulturhus).

Table 1. Recipe of the UNICON concrete

Materialer	kg/m^3
Norcem STDFA	364,2
Elkem Microsilica 940U (A-4066)	19,1
Fly ash (A-4076)	0,0
Fritt vann	193,0
Hembre 0-10	1156,9
Fossberga 8-16	638,0
Glenium SKY 601	4,37
Prop. betongdens. (kg/m^3)	2380

The concretes were mixed in a forced pan mixer with a volume of 50 litres from Eirich. The volume of the concretes batches was 55 litres. The initial mixing procedure was:

- 1 minute dry mixing of powders and aggregates
- 2 minutes while adding mixing water and approximately the amount of superplasticizer
- 2 minutes pause/rest
- 2 minutes mixing with addition of remaining superplasticizer until target slump flow value was reached.

After the SU measurement, testing with the three other methods started at the same time, 10 minutes after water addition. The concrete was taken out of the mixer with a 5 litre pitcher to fill up 10 litre buckets to be carried some meters to the Pipe and to the T-Box (two buckets needed for the T-Box; 16 litres). The rheometer container was filled directly with the pitcher. Light hand mixing with a ladle in the buckets was done immediately before pouring into the Pipe and T-Box.

The results, given in Table 2, show that both VSI and PDI/VI (T-Box) indicate good stability, which is in accordance with the experience using the concrete on site (Stjørdal kulturhus). Increasing the SU (by increasing the amount of superplasticer) resulted in increasing VSI, but did not consistently influence SPI and PDI/VI.

The T-Box ranks all concretes as stable. Note that the measured T-Box penetration of the SU=750 mm concrete was higher before the test than after, giving a negative PDI. We have not found whether this is result of a measuring error or not.

The Pipe Test ranks all concretes as instable. Note however that the limit value for the test may be different from the one taken from the original Settlement Column Test. Three consecutive tests were executed (approximately 10 minutes interval). As can be seen, there is some variation in the results (as in the "running in test" described earlier). Note that when considering the first result of SU=725 mm concrete (0.83), the test indicates decreasing stability with increasing SU.

The RSI is fairly in accordance with the VSI^m, as is the experience from earlier work.

Table 2. Results (green and red indicate stable and instable concrete, respectively, according to the test methods)

Concrete	VSI^m	VSI^b	RSI	SPSI	T-Box	
					PDI	VI
	≤ 0.5	≤ 0.6	≤ 0.5	≥ 0.88*	≤ 6 mm	≤ 25 %
SU=670, t_{500} =1.5	0.5	0.2	na	0.85	4.5 mm	15 %
SU=725, t_{500} =1.3	0.6	0.35	0.68	0.83, 0.87, 0,80	4.5 mm	22 %
SU=750, t_{500} =1.1	0.75	0.5	na	0.80	**-3 mm!!**	20 %

* *According to the original Settlement Column Test*

APPENDIX 3

Results from field experiments 2014

Mix A

Time of water addition	10:20	
Arrival constr. site	10:50	
WRA added at mixing	1,21	% of binder

Adjustment of consistence

	Dosage [kg/m^3]	Slumpflow [mm]	t500 [s]	Density [kg/m^3]	Air [%]	Time
Adjustment 1	0,38	620				11:08
Adjustment 2	0,25	650				11:15
Adjustment 3	**0,13**	**700**	**0,78**	**2443**	**0,5**	**11:30**

VSI	**0,5/0,6**	**RSI**	**0,49**

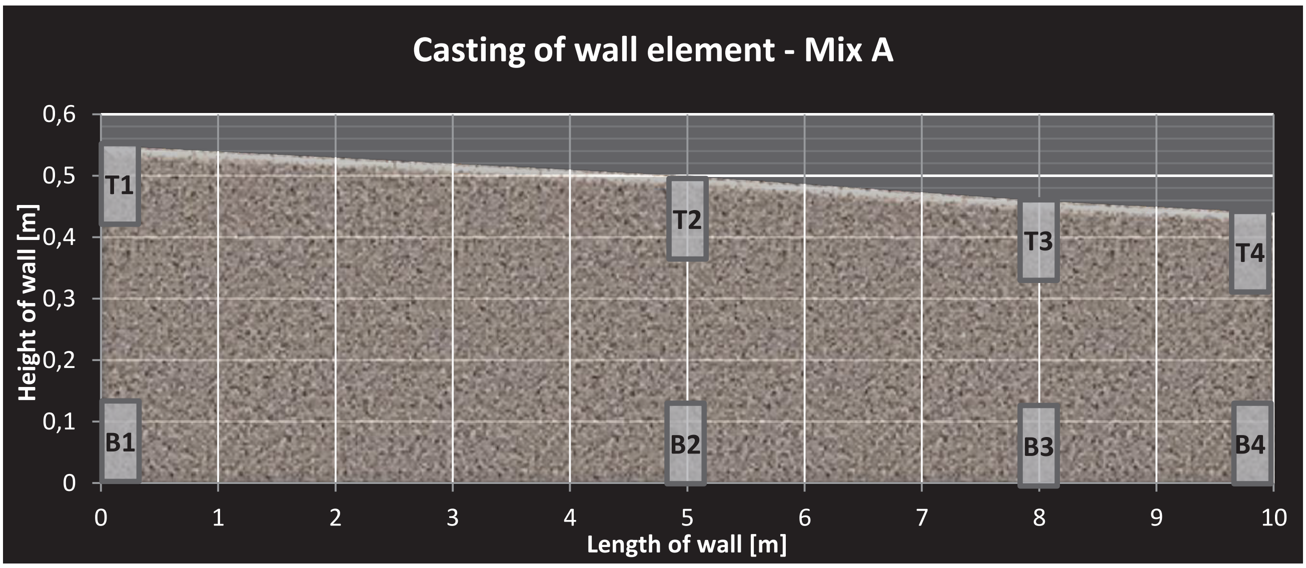
Casting of wall element

Time 11:35

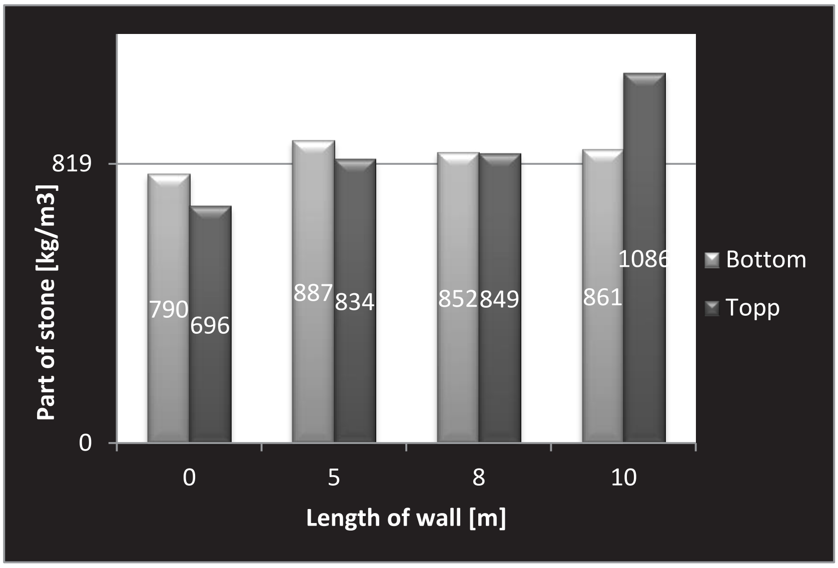
Position [m]	Height [m]
0	0,55
5	0,5
8	0,46
10	0,44

Sampling from wall element

Position	Weight [g]	Volume [m^3]	Washed [g]	Stone part [kg/m^3]	Stone part recipe [Kg/m^3]	SI_{beam}
T1	13811	0,0057	3976	696	819	0,85
B1	13694	0,0057	4474	790		0,96
T2	13587	0,0056	4686	834		1,02
B2	12255	0,0051	4498	887		1,08
T3	13062	0,0054	4588	849		1,04
B3	13381	0,0055	4718	852		1,04
T4	12790	0,0053	5747	1086		1,33
B4	12339	0,0051	4398	861		1,05



Position [m]	Topp [Kg/m^3]	Bottom [Kg/m^3]	SI_{topp}	SI_{bottom}
0	696	790	0,85	0,96
5	834	887	1,02	1,08
8	849	852	1,04	1,04
10	1086	861	1,33	1,05



T-box

Before tilting	Penetration	77,0	mm
	Penetration	75,0	mm
	PDI	**2,0**	**mm**
After tilting	Penetration	106,0	mm
	Penetration	100,0	mm
	PDI	**6,0**	**mm**

Volume calculations		V_{TU}		V_{TD}	
Total height of T-box		280	mm	280	mm
	x_1	*217*	*mm*	*180*	*mm*
	x_2	*219*	*mm*	*183*	*mm*
	x_3	*219*	*mm*	*182*	*mm*
	x_4	*221*	*mm*	*182*	*mm*
Height from top to concrete, X		219	mm	181,75	mm
Height of concrete		0,61	dm	0,98	dm
Area of concrete (2x2)		4,00	dm	4,00	dm
Volume of concrete		**0,00244**	**m^3**	**0,00393**	**m^3**

Sampling from T-box

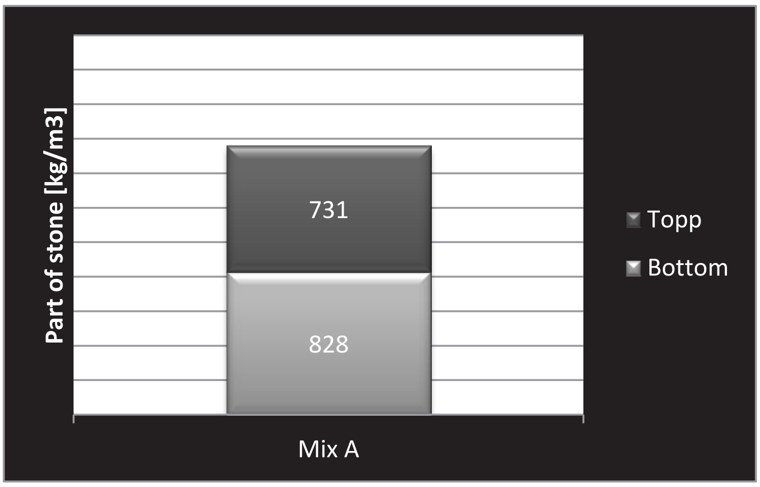
Position	Volume, *V* m^3	Washed, *m* g	Stone part kg/m^3
TU	0,0024	2199	901
TD	0,0039	3711	944

ρ_{tils} 2680 kg/m^3

VS	**4,66**

Settlement coloumn test

	Topp		Bottom	
Volume	2,65	dm^3	2,65	m^3
Stones	1939	g	2195	kg
Stone part	731	kg/m^3	828	kg/m^3



Mix B

Time of water addition 13:00
Arrival constr. site 13:30
WRA added at mixing 1,44 % of binder

Adjustment of consistence

	Dosage	Slumpflow	t500	Density	Air	Time
	[kg/m^3]	[mm]	[s]	[kg/m^3]	[%]	
Adjustment 1	**0,50**	**740**	**< 0,47**	**2417**	**0,1**	**14:00**

VSI	**0,7/0,8**
RSI	**0,91**

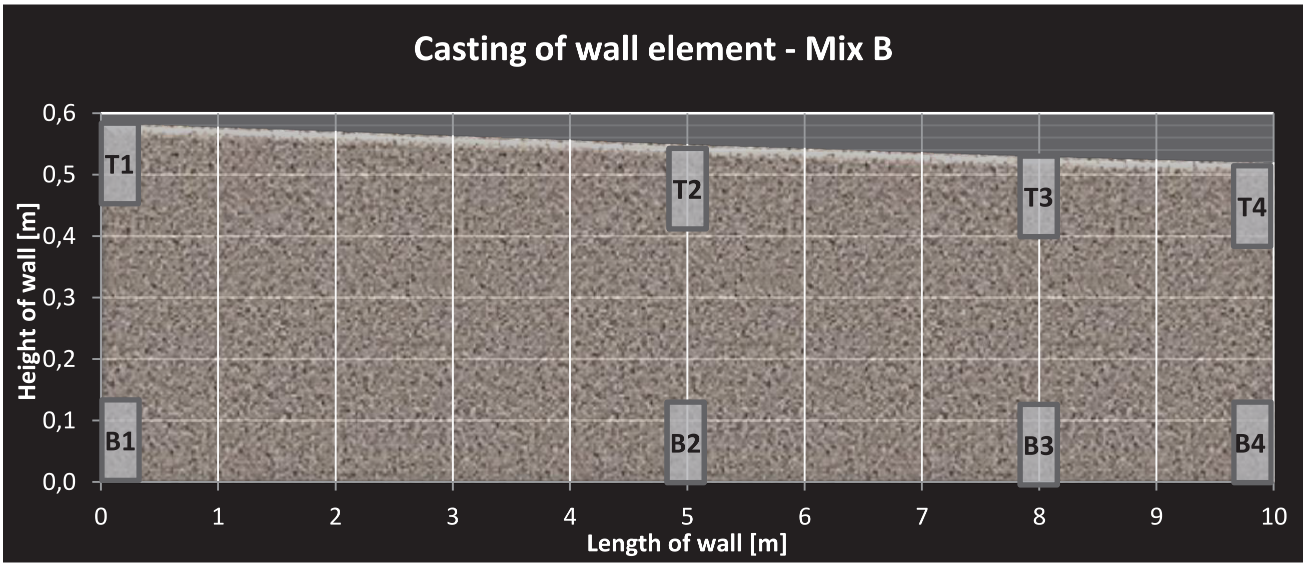
Casting of wall element

Time 13:55

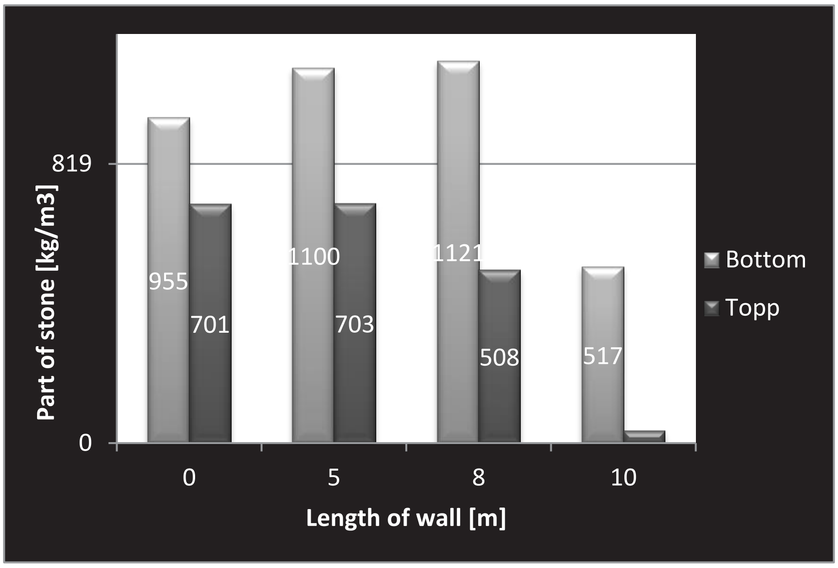
Position [m]	Height [m]
0	0,59
5	0,55
8	0,53
10	0,52

Sampling from wall element

Position	Weight [g]	Volume [m^3]	Washed [g]	Stone part [Kg/m^3]	Stone part recipe [Kg/m^3]	SI_{beam}
T1	13647	0,0056	3958	701	819	0,86
B1	11472	0,0047	4533	955		1,17
T2	13481	0,0056	3921	703		0,86
B2	14212	0,0059	6468	1100		1,34
T3	13370	0,0055	2811	508		0,62
B3	13257	0,0055	6148	1121		1,37
T4	12811	0,0053	193	36		0,04
B4	13085	0,0054	2800	517		0,63



Position [m]	Topp [Kg/m^3]	Bottom [Kg/m^3]	SI_{topp}	SI_{bottom}
0	701	955	0,86	1,17
5	703	1100	0,86	1,34
8	508	1121	0,62	1,37
10	36	517	0,04	0,63



T-box

Before tilting	Penetration	75,5	mm
	Penetration	66,0	mm
	PDI	**9,5**	**mm**
After tilting	Penetration	84,5	mm
	Penetration	81,0	mm
	PDI	**3,5**	**mm**

Volume calculations	V_{TU}	V_{TD}
Total height of T-box	280 mm	280 mm
x_1	*210 mm*	*192 mm*
x_2	*208 mm*	*195 mm*
x_3	*208 mm*	*194 mm*
x_4	*210 mm*	*196 mm*
Height from top to concrete, X	209 mm	194,25 mm
Height of concrete	0,71 dm	0,86 dm
Area of concrete (2x2)	4,00 dm	4,00 dm
Volume of concrete	**0,00284 m^3**	**0,00343 m^3**

Sampling from T-box

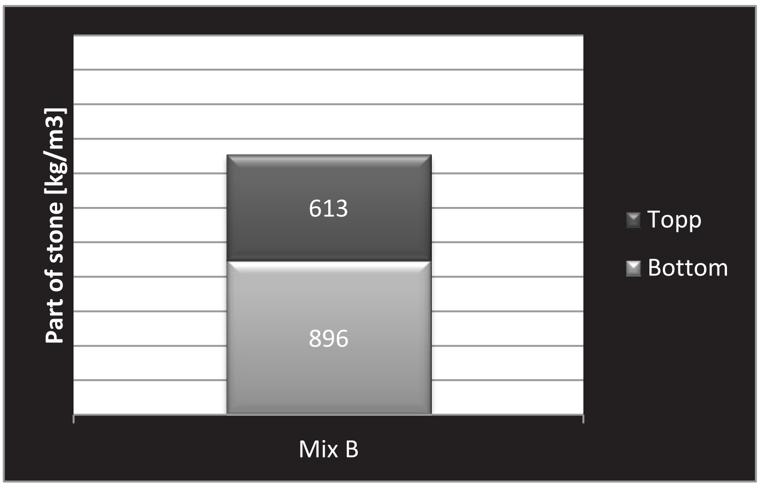
Position	Volume, *V* m^3	Washed, *m* g	Stone part kg/m^3
TU	0,0028	2726	960
TD	0,0034	3338	973

ρ_{tils} 2680 kg/m^3

VS 1,38

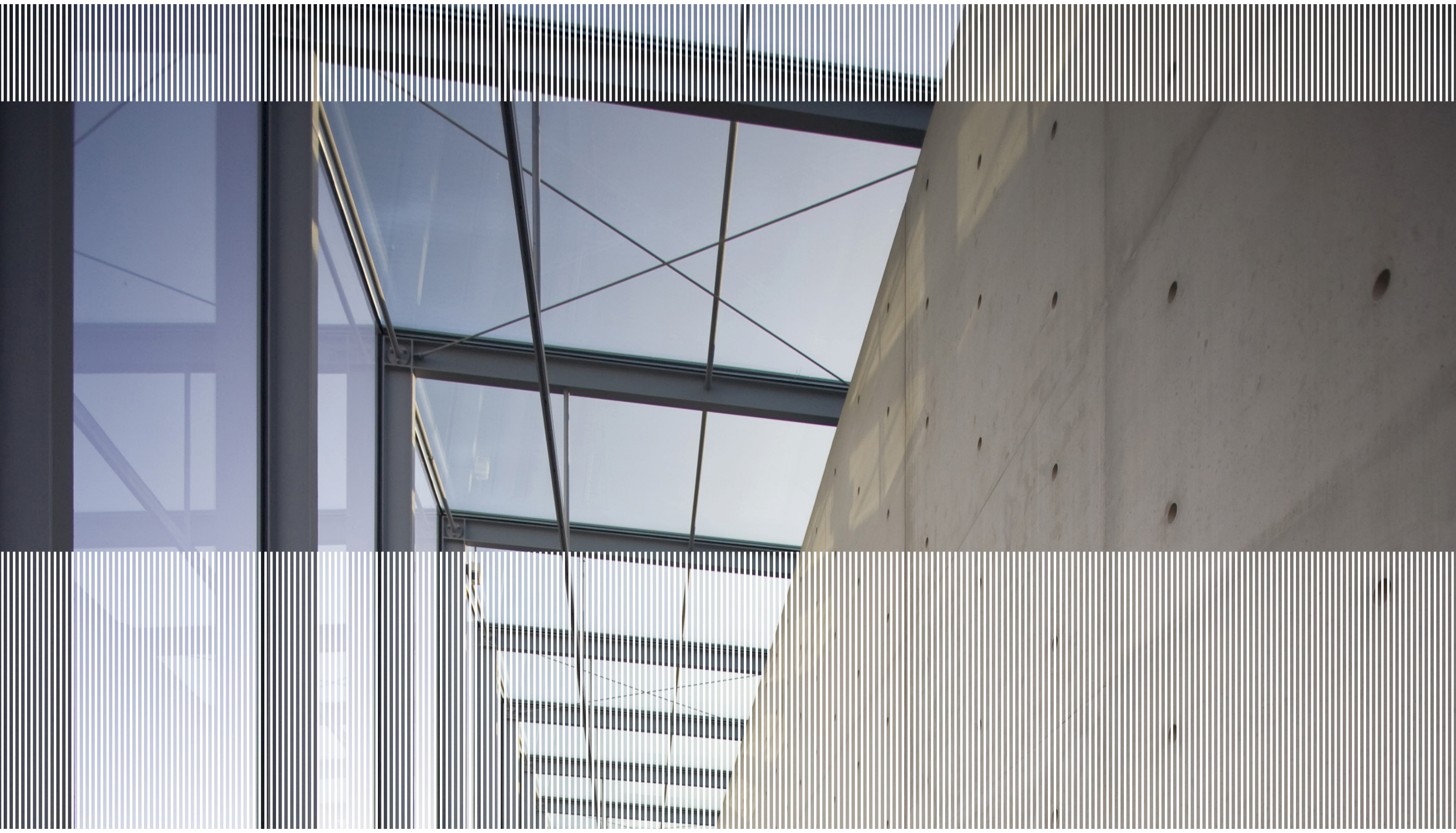
Settlement coloumn test

	Topp	Bottom
Volume	2,65 m^3	2,65 m^3
Stones	1624 kg	2376 kg
Stone part	613 kg/m^3	896 kg/m^3



SINTEF Building and Infrastructure is the third largest building research institute in Europe. Our objective is to promote environmentally friendly, cost-effective products and solutions within the built environment. SINTEF Building and Infrastructure is Norway's leading provider of research-based knowledge to the construction sector. Through our activity in research and development, we have established a unique platform for disseminating knowledge throughout a large part of the construction industry.

COIN – Concrete Innovation Center is a Center for Research based Innovation (CRI) initiated by the Research Council of Norway. The vision of COIN is creation of more attractive concrete buildings and constructions. The primary goal is to fulfill this vision by bringing the development a major leap forward by long-term research in close alliances with the industry regarding advanced materials, efficient construction techniques and new design concepts combined with more environmentally friendly material production.



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