Bundesanstalt für Wasserbau

Kompetenz für die Wasserstraßen

BAW Code of Practice

Segregation sensitivity of concrete (MESB)

2025 edition

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Kompetenz für die Wasserstraßen

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BAW Codes of Practice, Recommendations and Guidelines

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Federal Waterways Engineering and Research Institute (BAW)
Kußmaulstraße 17
76187 Karlsruhe

Postfach 21 02 53
76152 Karlsruhe

Tel.: 0721 9726-0

info@baw.de
www.baw.de

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Preliminary remark

To date, the concrete regulations do not contain any rules on the assessment of the segregation of concrete. Against this background, the BAW Code of Practice on the segregation sensitivity of concrete (MESB) deals with the assessment of vibrated concretes with regard to their sensitivity to segregation. The focus is on sedimentation of coarse aggregate and mortar accumulation and other segregation. The Code of Practice so far contains only specifications for the assessment of component samples; for the performance of fresh and hardened concrete tests on separately produced samples, the Code of Practice currently contains only recommendations.

With regard to the recommendations for fresh and hardened concrete tests on separately manufactured test specimens, the Code of Practice differentiates between tests on fresh concrete (washout test) and on hardened concrete (laboratory test specimen, small component, component drill core). The washout test as well as the hardened concrete tests on the laboratory test specimen and the small component are, according to the current state of the art, procedures with which initial practical experience has been obtained. These procedures are therefore listed in informative annexes until further notice. In the future, the washout test should enable concrete to be classified with regard to its sedimentation sensitivity. To this end, the transferability of the results of the washout test to practical conditions must be checked. This is to be achieved by comparison with tests on small components where the same concrete is compacted in line with current practice. The classification of concrete with regard to sedimentation sensitivity is intended to assist the user in selecting appropriate concrete compaction with reference to DIN 1045-3, 9.5 (1) and (7).

Goods lawfully marketed in another Member State of the European Union or in Türkiye, or originating and lawfully marketed in an EFTA State that is a contracting party to the Agreement on the European Economic Area, are deemed to be compatible with this measure. The application of this measure is subject to Regulation (EC) No 764/2008 of the European Parliament and of the Council of 9 July 2008 laying down procedures relating to the application of certain national technical rules to products lawfully marketed in another Member State and repealing Decision No 3052/95/EC (OJ L 218, 13.8.2008, p. 21).

1 Introduction

The analysis of the hardened concrete using drill cores taken from structural elements in accordance with Section 4.3 is intended to assess the extent of sedimentation of the coarse aggregate and of mortar accumulations or other segregations. This procedure and its associated criteria are set out in the BAW-MESB and are primarily used to check and evaluate the performance of construction work carried out.

The testing of fresh concrete in accordance with Section 3 and the testing of hardened concrete for the laboratory test specimen in accordance with Section 4.1 are based on the washout test in accordance with the DAfStb Guideline on self-compacting concrete, November 2003 edition, Annex N.2, or the sedimentation stability testing of hardened concrete in accordance with Annex N.1. The purpose of these investigations is to examine the sensitivity of concrete to the sedimentation of coarse aggregate during compaction. The test execution was adapted to the examination of vibrated concrete. The modifications concern, in particular, the inclusion of compaction in the testing process and the evaluation method.

The investigation of hardened concrete on the small component in accordance with Section 4.2 is intended to record, in a practical test, the effects of compaction by means of internal vibrators on the sedimentation of coarse aggregate and on mortar accumulations and other segregations. This test also serves to gather experience with regard to the transferability of the results of the washout test to construction practice.

2 Literature and normative references

DAfStb Guideline	Self-compacting concrete (SVB guideline), November 2003 edition
DBV Reference document	Special procedures for testing fresh concrete
DIN 1045-3	DIN 1045-3:2023-08, Concrete, reinforced concrete and prestressed concrete structures – Part 3: Construction work
DIN EN 12350-1	Testing fresh concrete – Part 1: Sampling
DIN EN 12350-5	Testing fresh concrete – Part 5: Extent of expansion
DIN EN 12350-6	Testing fresh concrete – Part 6: Bulk density of the fresh concrete
DIN EN 12350-7	Testing fresh concrete – Part 7: Air content - Pressure methods
DIN EN 12620	Aggregates for concrete
DIN ISO 3310-2	Test sieves — Technical requirements and testing — Part 2: Test sieves of perforated metal plate
BAW Code of Practice	Drill core sampling for inspection of construction work (MBK)

3 Tests on fresh concrete

See Annex A

4 Tests on hardened concrete

4.1 Laboratory test specimens

See Annex B

4.2 Small component tests

See Annex C

4.3 Tests on component drill cores

4.3.1 Short description

The testing of the drill core is used to assess the sedimentation of the coarse aggregate of concrete with a maximum grain size of at least 16 mm and of mortar accumulations or other segregation of concrete with any maximum grain size under the given installation conditions. The procedure can be used for different objectives. The testing is carried out analogously to the DAfStb-SVB Guideline, Annex N.1, by means of a visual assessment of the distribution of coarse aggregate on the core cross section, supplemented by a quantitative determination of the coarse grain distribution. In addition, the drill core surface is assessed for mortar accumulations and other segregations.

4.3.2 Equipment

4.3.2.1 Drilling equipment

For drill core sampling according to BAW-MBK.

4.3.2.2 Saw

Suitable for sawing the drill cores along the drill core axis.

4.3.2.3 Template

Suitable for recording the cut surfaces of the coarse aggregate relevant for the evaluation in accordance with Section 4.3.4.1.

4.3.2.4 Pen

Used to mark the cut surfaces of the coarse aggregate relevant to the evaluation or an equivalent marking method.

4.3.2.5 Video recorder

Used to create a digital image of the test specimen.

4.3.3 Performance

4.3.3.1 Sampling

Drill cores are sampled in accordance with BAW-MBK. The drill core diameter is preferably 150 mm with a minimum length of 450 mm. Depending on the component edge conditions (reinforcement distance), the diameter may be reduced to 100 mm. In the case of drill cores taken horizontally, the orientation in the component must be indicated on the drill core.

Note: A reduction to a drill core diameter of 100 mm must be critically questioned due to the reduced absolute area of the cut aggregate available for evaluation and weighed against any restrictions on drill core sampling.

4.3.3.2 Sawing the test specimens

The drill core is to be sawn in the middle longitudinal to the drilling direction. After sawing, the cut surface of the drill core must be photographed.

4.3.3.3 Establishment of evaluation ranges

Three evaluation ranges with a length of 150 mm each shall be defined for each test in the longitudinal direction of the drill core. Evaluation selection must be done in a comprehensible manner, taking into account the overall impression of the test specimen. The location of each of the three ranges for each assessment area shall be indicated. Examples can be found in Figure 1.

Investigations with regard to the vertical sedimentation of coarse aggregate and of mortar accumulations or other segregations are usually carried out on drill cores to be taken vertically from the component. Existing concreting layers or concreting sections, if recognisable, must be taken into account when determining the evaluation ranges.

Investigations with regard to segregation processes perpendicular to the concreting height are normally carried out on cores to be taken horizontally from the component.

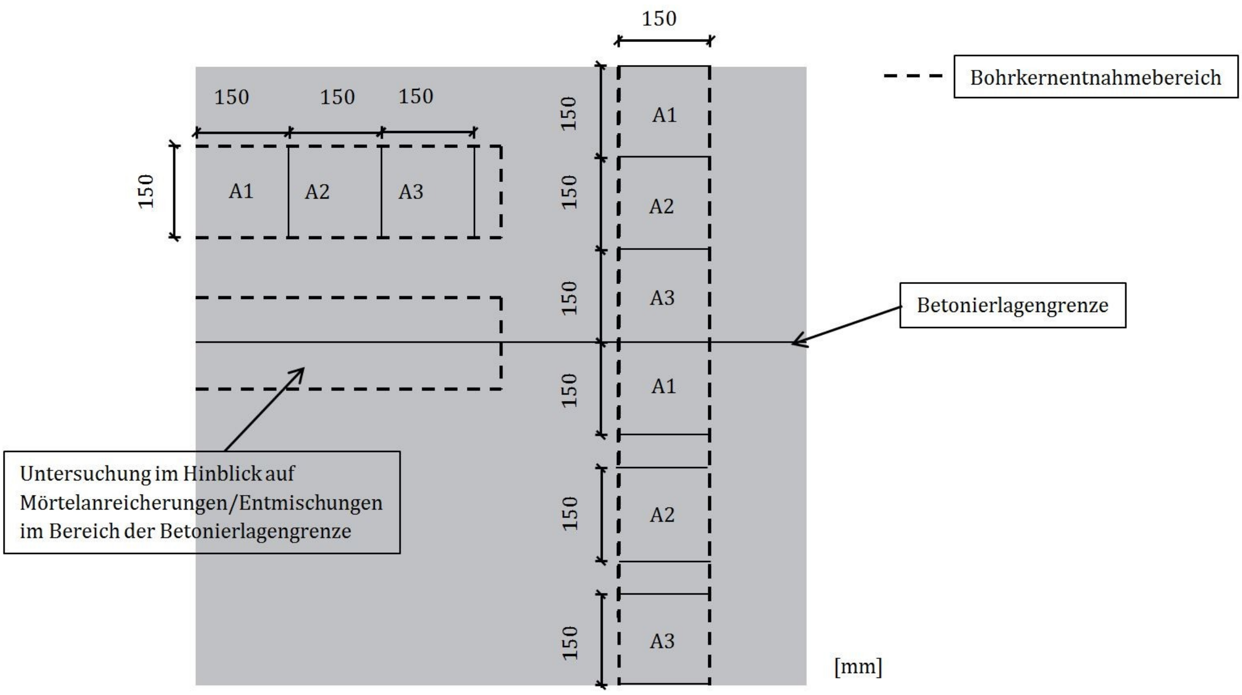


Figure 1: Examples for the establishment of evaluation ranges

Untersuchung im Hinblick auf Mörtelanreicherungen/Entmischungen im Bereich der Betonierlagengrenze	Investigation with regard to mortar accumulations/segregations in the area of the concreting layer boundary
Bohrkernentnahmebereich	Drill core sampling area
Betonierlagengrenze	Concreting layer boundary

4.3.3.4 Preparation of test specimens

For each evaluation range, all aggregates with a maximum dimension d on the sawn aggregate area of at least 8 mm shall be manually identified. The cut surfaces of these aggregates are to be marked throughout, e.g. by black staining. A digital image of the subsurfaces including a measuring rod must then be created and the surface dimensions of the evaluation ranges must be recorded.

Alternative methods for identifying the cut aggregates ≥ 8 mm are permitted provided that their equivalence is demonstrated.

4.3.4 Evaluation

4.3.4.1 Method

For the evaluation, the area of the cut aggregates ≥ 8 mm is to be determined to the nearest mm^2 for each of the three evaluation ranges. The procedure for determining the area of the marked aggregates is voluntary and must be presented in a comprehensible manner in the report.

From the areas of the three evaluation ranges, the mean area of the coarse cut aggregate ≥ 8 mm in the evaluation ranges must be calculated accurately to nearest mm^2.

$$\overline{A}=\frac{1}{3}\left(A_1+A_2+A_3\right)$$

Where:

$\overline{A}$	Mean area of the coarse cut aggregate ≥ 8 mm in the three evaluation ranges in mm^2
A_1, A_2, A_3	Area of the coarse cut aggregate ≥ 8 mm in the three evaluation ranges in mm^2

The percentage deviation of the area of the cut coarse aggregate ΔA_i in % in the individual evaluation range from the mean area shall be calculated to the nearest 0.1 %:

$$\Delta A_i=\left(\frac{A_i}{\overline{A}}-1\right)\cdot 100$$

Where:

A_i	Area of the coarse cut aggregate in the evaluation range i in mm^2
ΔA_i	Deviation of the area of the coarse aggregate in the evaluation range i from the mean area in %

4.3.4.2 Evaluation example

Figure 2 and Table 1 show an example evaluation for the area evaluation of the hardened concrete.

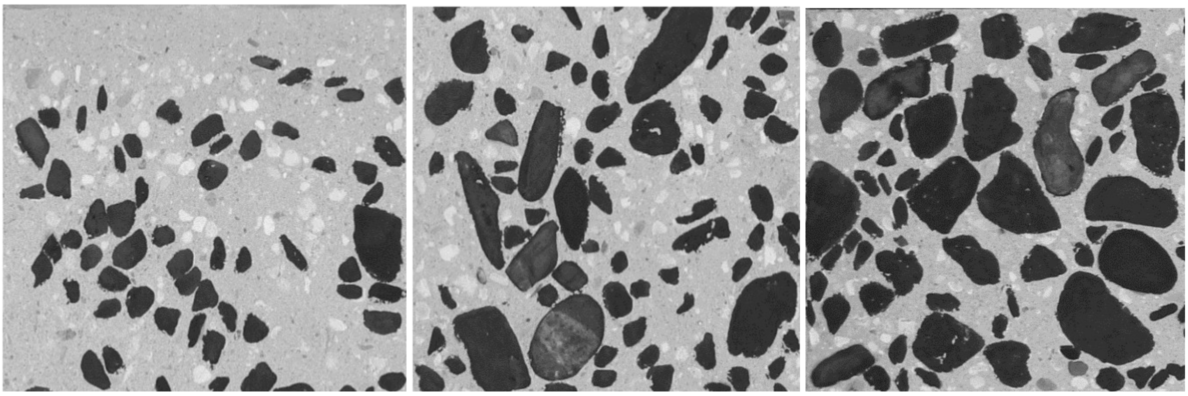


Figure 2: marked in black: cut aggregate areas ≥ 8 mm as a basis for the area evaluation (left: upper third, middle: middle third, right: lower third of a drill core)

Table 1: Evaluation of the areas sections from Figure 2

		A_i	ΔA_i
		[mm^2]	[%]
	1	2	3
1	Top	4198	-49
2	Middle	8593	+5
3	Bottom	11836	+44
4	Mean	8209	0

4.3.5 Assessment

When testing cores from components in accordance with Section 4.3, unless otherwise agreed, the following two assessment criteria are to be used as a yardstick for the identification of unduly sedimented or segregated areas of a concrete component:

- A deviation of ΔA_i = 30 % determined in accordance with Section 4.3.3 in conjunction with 4.3.4 must not be exceeded.
- There must be no undue mortar accumulation or other segregation in any area in the drill core. Undue mortar accumulation or other segregation occurs, inter alia, if:
    - the drill core surface has a circumferential strip with a width of at least 8 mm, in which only aggregates whose largest dimension d on the cut surface is 4 mm are present. In the area of concrete coverings, the concrete edge zone may be excluded from this evaluation up to a depth of 10 mm.
    - there is a circumferential, low-strength strip (separation layer) with e.g. porous areas on the drill core surface.

4.3.6 Report

The report must contain the following information and annexes:

a) a clear description of the drill core sampling point(s);

b) a unique designation of the test specimens investigated;

c) a photo of the drill cores with scale;

d) a unique identification of the evaluation ranges on the cut surface (photo);

e) a photo of the cut surface with the aggregates marked for evaluation;

f) a description of the procedure for determining the area sections of the aggregate in the evaluation ranges;

g) the mixing calculation and maximum grain size of the aggregate;

h) the limit dimension d of the aggregate proportions taken into account in the analysis;

i) the area of coarse aggregate A_i in each evaluation range in mm^2;

j) the mean area $\overline{A}$ in mm^2;

k) the percentage deviation of the coarse grain proportion ΔA_i in the individual evaluation ranges in %;

l) a description of any mortar accumulation and other segregation;

m) any deviation from the described test procedure;

n) drilling protocols in accordance with BAW-MBK;

o) the concreting plan, delivery notes and fresh concrete properties of the sampled area during concrete pouring (extent of expansion, fresh concrete bulk density, air content, fresh concrete temperature), if no information is available, this must also be indicated;

p) the date of concrete pouring;

q) the compactor used during concrete pouring and its diameter, frequency, manufacturer, type designation;

r) an indication of planned and/or actual compaction times; if no information is available, this must also be indicated.

Annexes

Annex A: Washout test (informative)

A.1 Short description

The washout test is used to evaluate the sedimentation sensitivity of vibrated concrete with a maximum grain size of at least 16 mm. The test determines the relationship between compaction time and sedimentation of the coarse aggregate.

During the washout test, three equally high cylinder segments are placed on top of each other, filled with concrete and compacted. Immediately afterwards, the mass of the sieve residue of the coarse grain proportion of the aggregate in the concrete in the respective cylinder segment is determined after washing out and sieving. The differences in the proportions of coarse aggregate on the individual sieves indicate the degree of segregation as a result of the compaction effect introduced.

A.2 Equipment

A.2.1 Timer

Measurement accuracy of 1 second.

A.2.2 Thermometer

Measurement accuracy: 1 °C.

A.2.3 Tap measure

Measurement accuracy: 1 mm.

A.2.4 Compactor

A unit consisting of a vibrating table, cylindrical mould, clamping device and control for time and frequency. The detachable cylindrical mould made of steel with a total height h_{tot}=450 mm consists of three equally high parts h_i=150 mm high with an inner diameter d=150 mm.

Note 1: The design of the compactor, the clamping of the cylindrical mould and the frequency and amplitude are decisive for the total energy input in the concrete and thus for the results obtained therewith. The investigations on the segregation sensitivity of concrete in the DAfStb fresh concrete working group were carried out with the device shown in Figure 3. At a frequency of 75 Hz, they have led to good differentiation. This compactor has an amplitude of 0.25 mm when the cylindrical mould is clamped and completely filled with concrete. In order to avoid harmonics, a certain minimum contact pressure of the cylindrical mould must be observed. In the tests carried out so far, this was the case from a tightening torque of 12 Nm on the clamping screws.

Note 2: The further development of the BAW-MESB requires the systematic collection of further experimental data. For this purpose, the BAW uses the equipment used in the DAfStb fresh concrete working group. Test data from third parties could contribute to this, but is currently only usable if it is obtained with the same test equipment and the same test parameters.

Frequency and amplitude parameters are to be measured and documented once a year for a defined pressed and completely filled cylindrical mould.

Figure 3: Compactor with clamped cylindrical mould filled with concrete

A.2.5 Scraping ruler

No more than 200 mm long.

A.2.6 Sieve plate

With 8 or 11.2 (11) mm square openings, a frame diameter of at least 300 mm and a height of at least 30 mm, in accordance with DIN ISO 3310-2.

A.2.7 Container

Made of non-absorbent material for holding the fresh concrete sample in accordance with DIN EN 12350-1.

A.2.8 Sample containers

Three sample containers made of non-absorbent material for holding the washed-out coarse aggregates from the three cylinder pieces.

A.2.9 Scales

Scales with a load capacity of at least 10 kg and with which the mass can be determined accurately to 0.001 kg.

A.2.10 Separation slide

Made of thin sheet steel and used to separate the individual segments filled with concrete after the test has been carried out.

A.3 Performance

A.3.1 Sampling

A sample representative of the batch to be evaluated in accordance with DIN EN 12350-1 is to be taken and filled into a container.

Note: The collection of a representative sample is of particular importance in the washout test, as this can have a direct impact on the test result.

A.3.2 Filling and compacting the cylindrical mould

The compactor is to be placed on a fixed horizontal surface. The cylindrical mould is then to be assembled. The concrete in the container is to be thoroughly mixed immediately prior to filling into the cylindrical mould to ensure a homogeneous particle distribution in the cylindrical mould. If the cylindrical mould is initially held at an angle, the concrete must be filled completely to the upper edge of the formwork, with as little cavity as possible without compaction. Excess concrete must be removed with a scraping ruler in a sawing motion, avoiding any compaction.

The cylindrical mould is to be fixed to the vibrating table defined with the intended tightening torque. The concrete is to be compacted with the specified parameters (see Sections A.5.2 and A.5.3). Refilling during the compaction process is not permitted. After completion of the compaction, the settling a of the concrete between the top edge of the cylinder and the surface of the compacted concrete is to be measured to an accuracy of 1 mm.

Note 1: Concrete with a low extent of expansion (lower F3 range and smaller) may result in a strong settling of the concrete in the cylindrical mould during the test. In this case, due to the fact that it is not possible to make exact thirds of the sample, a meaningful test evaluation in accordance with Section A.4 may no longer be possible.

Note 2: In order to carry out the tests referred to in Section A.5.2, it is necessary to fill at least four cylindrical moulds immediately in succession, then to compact them, and only then to start washing out in order to minimise the influence of any fresh concrete properties that may change during the duration of the test. After compaction, changes in the fresh concrete properties over time no longer affect the test result.

A.3.3 Choice of sieve set

In the case of a concrete with a maximum grain size of 16 mm, the coarse grain is washed out and sieved on a sieve with square, 8 mm openings in accordance with DIN ISO 3310-2; in the case of a concrete with a maximum grain size of 22.4 or 31.5 mm, the coarse grain is washed out and sieved on a sieve with square, 11.2 (11) mm openings.

Note: No experience is available for vibrated concretes with a maximum grain size of 8 mm.

A.3.4 Washing out the concrete

The cylinder is to be divided with the help of the separation slide. Each segment is to be emptied into a container. The respective concrete weight $m_{b,i}$ in the three segments is to be determined to an accuracy of 1 g.

The concrete is then to be placed on the sieve in accordance with Section A.3.3, washed out and sieved. The coarse grain remaining on the sieve is to be collected in a sample container for each segment. Excess water must be drained from the sample container. The masses m_1, m_2 and m_3 of the coarse surface moist aggregates from the three segments are to be determined to an accuracy of 1 g.

A.3.5 Accompanying fresh concrete tests

The temperature of the concrete is to be measured and recorded to an accuracy of 1 °C using a thermometer. The consistency of the concrete in accordance with DIN EN 12350-5, the bulk density in accordance with DIN EN 12350-6 and the air content in accordance with DIN EN 12350-7 are to be determined and recorded at the time of testing. In the case of concrete from a ready-mixed concrete plant, the water content of the fresh concrete is to be determined in a kiln test in accordance with the DBV Reference document on special procedures for testing fresh concrete.

Note: If the filling and compaction of the cylindrical shapes takes a longer period of time during tests in accordance with Section A.5.2 and thereby leads to changes in the consistency and, if applicable, the air content, these properties should be determined before and after the completion of the compaction process of all cylindrical moulds.

A.4 Test evaluation

A.4.1 General

Two evaluation procedures for determining the sedimentation of coarse aggregate are described below. The evaluation referred to in Section A.4.2 has been used in the previous investigations. This evaluation is the reference procedure. The alternative evaluation according to Section A.4.3 leads to a significant simplification of the testing, as the washout process is eliminated.

Note: To verify representative sampling, it is advisable to compare the mean mass of the coarse aggregate $\overline{m}$ in accordance with Section A.4.2 to the proportion resulting from the grading curve or the mean fresh concrete bulk density $\overline{\rho}$ in accordance with Section A.4.3 to the fresh concrete bulk density in accordance with DIN EN 12390-6. Where several washout tests are carried out, a comparison of the coarse aggregate $\overline{m}$ and the mean fresh concrete bulk density $\overline{\rho_b}$ indicates the comparability of the respective samples.

A.4.2 Determination of the extent of sedimentation (reference procedure)

The mass of the coarse aggregate in the upper segment is to be corrected by the settling a to an accuracy of 1 g according to the following formula:

$$m_{1,corr} = \frac{m_1}{1-\frac{a}{150}}$$

Where:

m_1 Mass of the sieved coarse aggregate from the upper segment in g

a Settlement of the concrete after compaction in mm

From the corrected mass of the upper segment and the masses of the remaining two segments, the mean mass of coarse aggregate in the segments is calculated to the nearest 1 g.

$$\overline{m} = \frac{1}{3}\left(m_{1,corr} + m_2 + m_3\right)$$

Where:

$\overline{m}$	Mean mass of coarse aggregate in the three segments in g
$m_{1,corr}$	Corrected mass of coarse aggregate in the top segment in g
m_2, m_3	Mass of coarse aggregate in the middle and lower segments in g

The extent of sedimentation as a percentage deviation of the coarse grain proportion Δm_i in % by mass in the individual segment i from the mean coarse grain proportion is calculated to an accuracy of 1 % by mass:

$$\Delta m_i = \left(\frac{m_i}{\overline{m}} - 1 \right) \cdot 100$$

Where:

m_i	Mass of coarse aggregate in the three individual segments i in g
Δm_i	Percentage deviation of the coarse grain proportion in the individual segment i from the mean coarse grain proportion in % by mass

A.4.3 Determination of the density difference (alternative procedure)

An alternative evaluation procedure is the density difference, which is the difference between the fresh concrete density in the upper and lower segments and the mean fresh concrete density.

$$\Delta \rho_o = \rho_o - \overline{\rho}$$

$$\Delta \rho_u = \rho_u - \overline{\rho}$$

Where:

$\Delta \rho_o, \Delta \rho_u$	Density difference in the upper (o) or lower (u) segment in kg/m^3
ρ_o, ρ_u	Fresh concrete bulk density in the upper (o) or lower (u) segment in kg/m^3
$\overline{\rho} = \frac{\sum \rho_i}{3}$	Mean fresh concrete bulk density of the concrete of the three individual segments in kg/m3
$\rho_{i = \frac{m_{b,i}}{V_i}}$	Fresh concrete bulk density in the three individual segments i in kg/m^3
$m_{b,i}$	Mass of concrete in the three individual segments in kg
$V_i = \pi \cdot r^2 \cdot h_i$	Concrete volume in the three individual segments i in m^3
r	Radius of the individual segments, r=0.075 m
h_i	Height of the individual segments, h_m=150 mm, h_u=150 mm, h_o=150 mm-a
a	Settlement of the concrete after compaction in mm

A.4.4 Evaluation example

Table 2 shows evaluation examples for the washout test.

Table 2: Evaluation examples for the washout test according to Section A.4.2 and A.4.3

				Procedure described in		Procedure described in		
		m_i	a	$m_{1,corr}$	Δm_i	$m_{b,i}$	V_i	ρ_i
		[g]	[mm]	[g]	[% by mass]	[g]	[dm^3]	[kg/m^3]
	1	2	3	4	5	6	7	8
1	Top	1686	8	**1784**	**-20**	**5714**	2.51	**2276**
2	Middle	**2036**	-	-	**-8**	**6204**	2.65	**2341**
3	Bottom	**2838**	-	-	**+28**	**6506**	2.65	**2455**
4	$\overline{m}$	-	-	**2219**	0	-	-	-
5	$\overline{\rho}$	-	-	**-**	-	-		2357
6	$\Delta\rho_o$							-81
7	$\Delta\rho_u$							+98

A.5 Evaluation

A.5.1 General

With the current state of knowledge, no limit values for sedimentation sensitivity can be set. The test results should in principle:

- compare different concrete compositions.
- detect production-related fluctuations in the sedimentation sensitivity of a concrete recipe.

A.5.2 Determination of the sedimentation sensitivity

The sedimentation sensitivity is to be determined by varying the compaction time in at least four tests. For this purpose, compaction times of 15, 30, 60 and 90 s are recommended. For air-entrained concrete, shorter time intervals may be sensible. For concretes without air entraining, longer compaction times up to 120 seconds may be sensible. With a regression taking into account the zero crossing as a value pair, the relationship between the compaction time and the extent of sedimentation is determined. The slope of the regression line is used as a measure of the sedimentation sensitivity of the coarse aggregate under boundary test conditions. The coefficient of determination R^2 of the regression is to be indicated.

These tests are to be carried out for representative results if possible with the same other fresh concrete properties (extent of expansion ± 20 mm, air content ± 0.5 % by volume). This is to be verified by accompanying fresh concrete tests in accordance with Section A.3.5.

Note 1: The test result is influenced by the fresh concrete properties. For the evaluation of the results, it is important to know these fresh concrete properties and, if necessary, how they change during the test execution until compaction. Therefore, they must be determined.

Note 2: With increasing compaction time, a concrete-dependent compensatory state of the extent of sedimentation can occur. In this case, the extent of sedimentation remains approximately in the same order of magnitude with increasing compaction time. The determined extents of sedimentation, which are determined after this compensatory state has been reached, no longer describe the sedimentation sensitivity and are therefore not taken into account when determining the slope of the regression line (see Figure 5, Figure 6). This makes it possible to make a meaningful determination of the slope of the regression line with coefficients of determination $R^2 > 0.90$.

In order to classify the concrete with regard to its sedimentation sensitivity, it seems possible, in the light of the current state of knowledge, to classify the concrete in three categories on the basis of the relationship between compaction intensity and extent of sedimentation (see Figure 4):

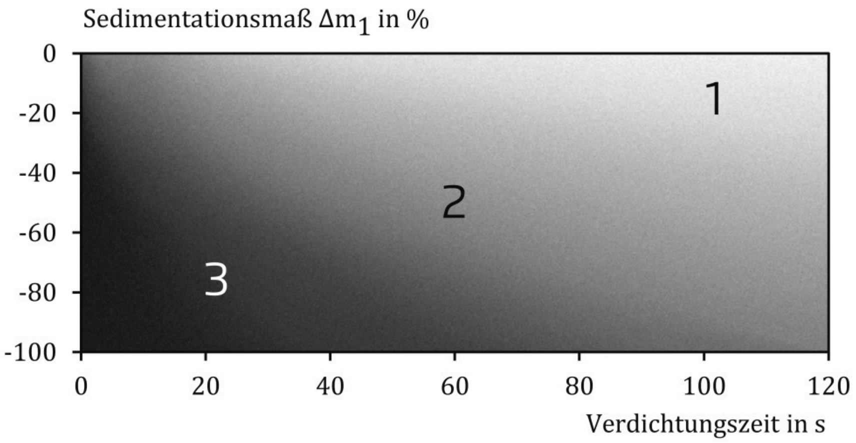
Category 1: rather low sensitivity to compaction

Category 2: Transition area

Category 3: rather higher sensitivity to compaction

The categories of different sedimentation sensitivity are intended to provide the user with information on the choice of appropriate concrete compaction. The sedimentation sensitivity is significantly influenced by concrete composition and the fresh concrete properties. According to the current state of knowledge, air-entrained concrete, for example, is more likely to be found in categories 2 or 3.

Note: A comparable area of experience is to be identified for the alternative evaluation procedure in accordance with A4.3 by means of further data collection.



Sedimentationsmaß Δm_1 in %	Extent of sedimentation Δm_1 in %
Verdichtungszeit in s	Compaction time in s

Figure 4: Ranges of different sedimentation sensitivities when evaluated in accordance with A.4.2

The coefficient of determination is calculated as follows:

$$R^2 = \frac{\sum \left(\hat{y}\left(x_i\right) - \overline{y}\right)^2}{\sum \left(y_i - \overline{y}\right)^2}$$

Where:

R^2 Coefficient of determination

$\hat{y}\left(x_i\right)$ Regression function

$\overline{y}$ Mean

y_i Test value

A.5.3 Manufacturing or on-site test of sedimentation sensitivity

The tests must be carried out with the same device at the same frequency and amplitude as the tests in Section A.5.2. It is advisable to use a compaction time in accordance with Section A.5.2 to carry out the washout test, where an extent of sedimentation of more than 20 % was determined for the tested concrete in the tests described in Section A.5.2. Shorter compaction times are also possible, but may lead to higher test variations in terms of results. The evaluation is carried out according to Section A.4.

In addition, the accompanying fresh concrete tests are to be carried out in accordance with Section A.3.5.

A.5.4 Evaluation example

An example for determining the relationship between compaction time and sedimentation of coarse aggregate in the upper segment is shown in Figure 5. An example of the relationship between the compaction time and the density difference is shown in Figure 6.

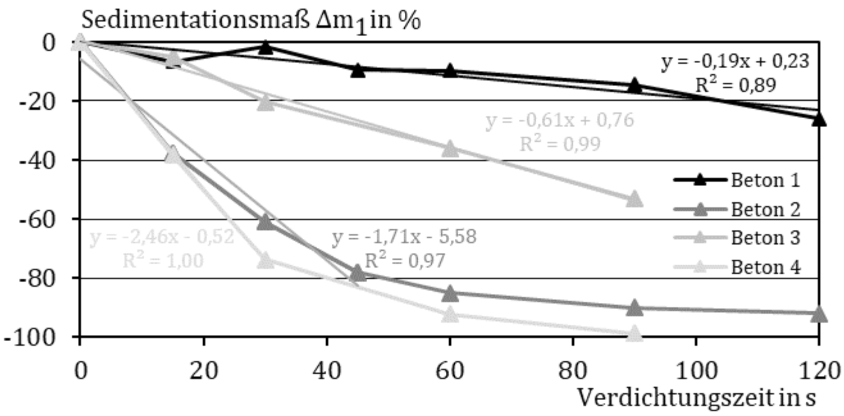
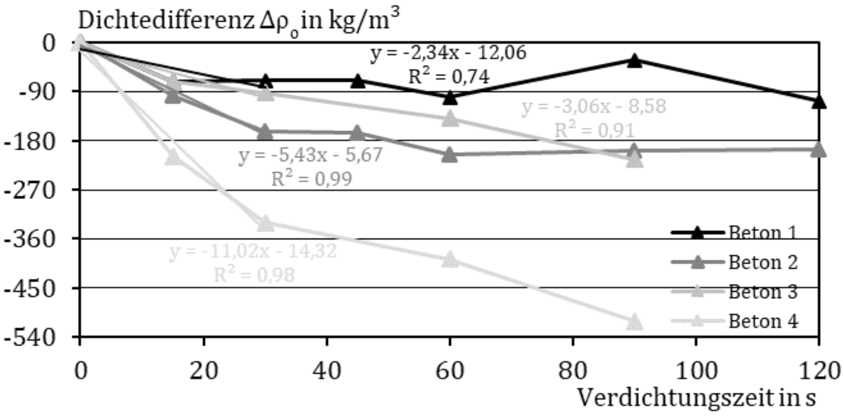


Figure 5: Example: Relationship between compaction time and sedimentation of coarse aggregate in the upper segment



Dichtedifferenz $\Delta\rho_o$ in kg/m³	Density difference $\Delta\rho_o$ in kg/m³
Verdichtungszeit in s	Compaction time in s

Figure 6: *Example: Relationship between compaction time and the difference between the fresh concrete bulk density in the upper segment and the mean fresh concrete bulk density*

The slope of the regression line with a high coefficient of determination describes the sedimentation velocity, the achievement of a compensatory state (see e.g. concrete 1 and concrete 2 for the density difference) indicates an overall sedimentation potential.

A.6 Report

When evaluated in accordance with the reference procedure set out in Section A.4.2, the report is to contain the following information and annexes:

a) the designation of the test specimen;

b) the place where the testing was carried out;

c) the date and time of testing;

d) the mixture calculation;

e) the maximum aggregate grain size;

f) the concrete age in minutes after the addition of water when filling the cylinder;

g) the temperature of the concrete at the time of testing, rounded up to the nearest °C;

h) the extent of expansion of the concrete at the time of compaction, expressed in mm;

i) the air content in % by volume and the bulk density of fresh concrete in kg/m³ at the time of compaction;

j) In the case of concrete from a mixing plant: the water content of the fresh concrete by kiln drying in kg/m³;

k) the compression frequency in Hz, amplitude in mm and compression time in s;

l) the settling a of the concrete in the cylinder after compaction in mm;

m) the masses of coarse aggregate m_i in each segment i in g;

n) the corrected mass of coarse aggregate $m_{1,corr}$ in the uppermost segment in g;

o) the mean mass of coarse aggregate $\overline{m}$ in g;

p) the percentage deviation of the coarse grain proportion Δm_i in % by mass in the individual segment i;

q) a graphical representation of results, including the regression and coefficient of determination R^2;

r) the log of the last measurement of the frequency and amplitude of the device in accordance with Section A.2.4;

s) any deviation from the described test procedure;

t) a statement by the person responsible for the technical testing that the testing was carried out in accordance with this description, with the exception of the note under point (s);

u) For site-mixed or ready-mixed concrete: delivery note.

In the case of evaluation according to A.4.3:

v) the mean fresh concrete bulk density $\overline{\rho}$ of the concrete of the three individual segments;

w) the fresh concrete bulk density ρ_i in the three individual segments i;

x) the mass of the concrete $m_{b,i}$ in the three individual segments in g;

y) the density difference $\Delta\rho_o, \Delta\rho_u$ in the upper (o) or lower (u) segment.

Annex B: Determination of sedimentation of coarse aggregate on the hardened concrete – laboratory test specimen (informative)

B.1 Short description

The determination of the sedimentation of coarse aggregate on the laboratory test specimen is to be used for the visual and quantitative evaluation of the sedimentation of coarse aggregates of vibrated concrete with a maximum grain size of at least 16 mm. In the test, the effect of different compaction times on the sedimentation of the coarse aggregate can be determined.

Cylinder formwork is filled with concrete and compacted. After hardening, the concrete cylinders are sawn centrally along the axis. The evaluation of the coarse grain distribution is carried out over the test specimen height. Differences in the proportions of the coarse aggregate over the evaluation ranges indicate the degree of sedimentation of the coarse aggregate as a result of the compaction effect introduced.

B.2 Equipment

See Sections A.2.1 to A.2.5 and Sections 4.3.2.2 to 4.3.2.5 and:

B.2.1 Cylinder formwork

Cylinder formwork of dimension d/h = 150 mm/450 mm that can be fixed to the vibrating table according to Section A.2.4 with a defined contact pressure. The material of the cylinder formwork is to be specified in the report.

B.3 Performance

B.3.1 Sampling

Sampling is to be carried out in accordance with Section A.3.1, preferably together with sampling for the washout test.

B.3.2 Test specimen production

For comparison with the washout test described in Appendix A, two cylinders are to be used in accordance with Section B.2.1. These cylinders are be compacted with the same compression parameters as in the washout test in accordance with Section A.3.2.

Note: It is recommended to produce at least one cylinder with the shortest compaction time and one cylinder with the longest compaction time in order to visualize the range of coarse grain sedimentation.

B.3.3 Sawing the test specimens

Performance takes place in accordance with Section 4.3.3.2.

B.3.4 Preparation of test specimens

The test surface is to be divided into three equal sections. Preparation is to be carried out in accordance with Section 4.3.3.4.

B.4 Test evaluation

B.4.1 Procedure

The evaluation is to be carried out in accordance with Section 4.3.4.

B.4.2 Evaluation example

An example evaluation is given in Section .

B.5 Evaluation

The results of the washout test and the hardened concrete test on the laboratory test specimen are compared. In addition to a visual impression of the hardened concrete sample, a quantitative comparison between fresh and hardened concrete testing is possible. The visual impression on the hardened concrete as well as the test results can be further used to classify results obtained on drill cores in accordance with Section 4.3.

B.6 Report

The report must contain the following information and annexes:

a) a unique designation of the test specimens investigated;

b) the place where the testing was carried out;

c) the date and time of testing;

d) the mixing calculation and maximum grain size of the aggregate;

e) the concrete age in minutes after the addition of water when filling the cylinder;

f) the temperature of the concrete at the time of testing, rounded up to the nearest °C;

g) the extent of expansion of the concrete at the time of compaction, expressed in mm;

h) air content in % by volume and the fresh concrete bulk density at the time of compaction in kg/m^3;

i) In the case of concrete from a mixing plant: the water content of the fresh concrete by kiln drying in kg/m^3;

j) the compression frequency in Hz, amplitude in mm and compression time in s;

k) the material of the cylinder formwork;

l) a unique identification of the evaluation ranges on the cut surface (photo);

m) a photo of the cut surface with the aggregates marked for evaluation;

n) a description of the procedure for determining the area sections of the aggregate in the evaluation ranges;

o) the limit dimension d of the aggregate proportions taken into account in the analysis, expressed in mm;

p) the area of coarse aggregate A_i in each evaluation range in mm^2;

q) the mean area $\overline{A}$ in mm^2;

r) the percentage deviation of the coarse grain proportion ΔA_i in the individual evaluation ranges in %;

s) a description of any mortar accumulation and other segregation;

t) any deviation from the described test procedure;

u) a statement by the person responsible for the technical testing that the testing was carried out in accordance with this description, with the exception of the note under point t);

v) For site-mixed or ready-mixed concrete: delivery note.

Annex C: Testing of sedimentation of coarse aggregate on hardened concrete – small component (informative)

C.1 Short description

The determination of the sedimentation of the coarse aggregate on the small component is used for the visual and quantitative assessment of the sedimentation of the coarse aggregate of vibrated concrete with a maximum grain size of at least 16 mm. In the test, the effect of practical compaction using an internal vibrator at different compaction times on the sedimentation of the coarse aggregate can be concluded.

Two identical formwork units are filled with concrete and compacted by means of internal vibrators with different vibration durations. After hardening, drill cores are taken and sawn along the middle of the axis. The coarse grain distribution is evaluated over the test specimen height. Differences in the proportions of coarse aggregate over the test sections indicate the degree of segregation as a result of the compaction effect introduced.

C.2 Equipment

See Sections A.2.1 to A.2.3 and Sections 4.3.2.1 to 4.3.2.5 and:

C.2.1 Formwork

Column formwork with a diameter of 800 mm and a height of approx. 600 mm with smooth formwork skin.

C.2.2 Internal vibrator (poker vibrator)

Internal vibrator with a diameter of between 50 and 60 mm for concrete compaction in the small component.

C.3 Performance

C.3.1 Sampling

A sample representative of the batch to be assessed is to be used, with a consistency representative of the concrete and, in the case of air-entrained concrete, a representative air content from a truck mixer.

C.3.2 Small component production

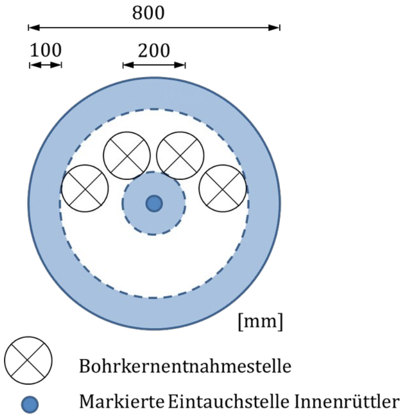
Two small components are to be produced using the formwork in accordance with Section C.2.1. The concrete is to be placed in the first small component in a concrete layer at a height of approximately 500 mm (in the compacted state) and compacted using an indoor smelter as defined in section C.2.2 in accordance with the generally recognised state of the art. The selected compaction time per layer must be documented. The second small component is to be manufactured in the same way, but with three times the compaction time. The immersion point of the poker vibrator is to be placed in the centre of both components and marked.

C.3.3 Accompanying concrete investigations

In addition to small component production, the washout test according to Section 3 and the hardened concrete test according to Section 4.1 are to be carried out.

C.3.4 Drill core sampling

After sufficient hardening, the entire small component must be drilled vertically. Drill core sampling must be carried out in accordance with the BAW Code of Practice on drill core sampling. To compare the evaluations of the two components, the drill core sampling points on both components must be selected and documented in the same places. The sampling points should be 10 cm outside the centre of the immersion site of the internal vibrator, leaving an edge area of 10 cm for the formwork and should cover the entire cross section of the component. At least three core samples are to be taken. A recommendation for drill core sampling can be found in Figure 7.



Bohrkernentnahmstelle	Drill core sampling point
Markierte Eintauchstelle Innenrüttler	Marked internal vibrator immersion point

Figure 7: Recommendation for drill core sampling points on the small component (top view)

C.3.5 Sawing the test specimens

Performance takes place in accordance with Section 4.3.3.2.

Note: Depending on the visually determined impression of the microstructure, at least one representative drill core per component must be sawn for further evaluation.

C.3.6 Establishment of evaluation ranges

The test surface is to be divided into three equal sections.

C.3.7 Preparation of test specimens

Preparation is to be carried out in accordance with Section 4.3.3.4.

C.4 Test evaluation

C.4.1 Procedure

The evaluation is to be carried out in accordance with Section 4.3.4.1.

C.4.2 Evaluation example

An example evaluation is given in Section .

C.5 Evaluation

The investigations of the small components should show the effects of significantly different compaction times on the segregation tendency of the concrete in the component using an internal vibrator.

Note: The investigations of the small component are intended to provide insight into the transferability of the results of the washout test to practical conditions. For this purpose, the results of the washout test (Section 3) and the laboratory test specimens (Section 4.1) are to be compared with the results of the small components. In future, the user should be able to derive conclusions for the processing of the concrete.

C.6 Report

The report must contain the following information and annexes:

a) a clear description of the small component including photos;
b) clear identification of the position of the insertion point of the internal vibrator;
c) the type designation and characteristic values of the internal vibrator;
d) the chosen compaction time per immersion process for both components;
e) a clear description of the drill core sampling point;
f) a unique designation of the test specimens investigated;
g) a photo of the drill cores with scale;
h) a comprehensible justification of the drill cores selected for the evaluation;
i) a unique identification of the evaluation ranges on the cut surface (photo);
j) a photo of the cut surface with the aggregates marked for evaluation;
k) a description of the procedure for determining the area sections of the aggregate in the evaluation ranges;
l) the mixing calculation and maximum grain size of the aggregate;
m) the limit dimension d of the aggregate proportions taken into account in the analysis;
n) the surface area of coarse aggregate A_i in each evaluation range in %;
o) the mean surface area $\overline{A}$ in %;
p) the percentage deviation of the coarse grain proportion ΔA_i in the individual evaluation ranges in %;
q) a description of any mortar accumulation and other segregation;
r) any deviation from the described test procedure;
s) the drilling logs according to the BAW Code of Practice on drill core sampling;
t) the delivery notes as well as fresh concrete properties during concrete pouring (extent of expansion, fresh concrete bulk density, air content, fresh concrete temperature); if no information is available, this must also be indicated;
u) the concrete age in minutes after loading time.