EVALUATION OF SEDIMENTATION STABILITY ON PROTOTYPE P-TYPE 6: ACCELERATION MEASUREMENT ON THE SHAKING TABLE

BEWERTUNG DER SEDIMENTATIONSSTABILITÄT AM PROTOTYP P-TYP 6: BESCHLEUNIGUNGSMESSUNG AM RÜTTELTISCH

Aylin Sabiha Geçgel

Institute of Construction Materials (IWB), University of Stuttgart

SUMMARY

The utilisation of concretes with high flowability presents a number of advantages, particularly in the context of complex construction projects. However, there are still challenges with regard to stability monitoring. The sieve test, as outlined in DIN EN 12350-11, is not suitable for practical use on construction sites, as it does not allow time-resolved monitoring of stability. A newly developed prototype, which is equipped with vertical vibrators and precise sensors for measuring moisture and acceleration, demonstrates a promising correlation between compaction parameters and concrete stability.

ZUSAMMENFASSUNG

Der Einsatz von Betonen mit hoher Fließfähigkeit bietet insbesondere bei komplexen Bauprojekten eine Vielzahl von Vorteilen. Allerdings bestehen nach wie vor Herausforderungen hinsichtlich der Stabilitätsüberwachung. Der gemäß DIN EN 12350-11 durchgeführte Siebversuch ist für den praktischen Einsatz auf Baustellen nicht geeignet, da er keine zeitaufgelöste Überprüfung der Stabilität erlaubt. Ein neu entwickelter Prototyp, der mit vertikalen Schwingungen und präzisen Sensoren zur Feuchtigkeits- und Beschleunigungsmessung ausgestattet ist, zeigt eine vielversprechende Korrelation zwischen Verdichtungsparametern und Betonstabilität.

1. TEST METHOD

1.1 Introduction and state of the art

The adaptable application of SCC, which encompasses a spectrum of demanding architectural projects and large-volume infrastructure buildings, has rendered the utilisation of highly flowable concretes a particularly appealing proposition. These concretes, frequently designated as "modern," are distinguished by their high flowability, which is attained through the incorporation of high-performance PCE superplasticisers (polycarboxylate ether). This enables the attainment of reduced water-to-cement ratios, which facilitates the production of ecologically optimised concretes or mass concretes [1].

Notwithstanding the technological advancements, historical projects illustrate that ensuring the stability of these concretes remains a challenge. This is due to the fact that SCC and lightweight compacted concrete (LCC) are more susceptible to environmental influences as a result of the highly effective superplasticisers. A further critical point is that the sieve test described in DIN EN 12350-11 is the only standardised method for testing sedimentation stability. However, this method is not suitable for construction sites and does not allow time-resolved measurements that could be applied directly on site.

The German Committee for Reinforced Concrete Construction (DAfStb) has already developed a promising approach for stability testing on construction sites in its guideline for SCC. In this method, a three-part cylinder is filled with concrete and then divided into three segments. The concrete is then washed through an 8 mm sieve, whereby the remaining aggregate is weighed and the average value of the three segments is calculated. The aggregate in the upper segment is deemed to deviate from the mean value by less than 20 % if it falls outside the range of plus or minus 20 % of the mean value [2].

Nevertheless, the duration of this test is approximately 30 minutes, a period of time that is frequently unavailable on construction sites and is therefore reluctantly employed. There is a necessity to either develop more efficient testing methods or to adapt the processes on construction sites accordingly to ensure the quality and stability of the concrete.

In recent years, a number of novel approaches have been developed to address this issue. Among the techniques that have emerged is a rapid test utilising a ball penetration method. This approach is described in reference [3], along with initial attempts to enhance the washout test in alignment with the DAfStb guidelines, with the aim of quantifying the degree of sedimentation within concrete [4–7]. It is particularly noteworthy that Spörel [7] was the first to combine the three-cylinder test with a vibrating table, thereby establishing the foundation for the subsequent development of prototypes, which are described in detail below.

Nevertheless, there is currently no recognised methodology for the monitoring of sedimentation, whether as part of the acceptance test on the construction site or as an extended initial test in the laboratory. Furthermore, there are no established test methods for easily compactable concrete, particularly in consistency classes F5 and F6, which are also referred to as modern concretes and are characterised by a very flowable consistency and a high admixture content [3].

1.1.1 Set-up of the P-Type 6 prototype

In the course of developing the measuring system, a number of prototypes were created, the findings of which are informing further research and development. The current prototype, designated P-Type 6, is illustrated in Fig. 1 and comprises a vibrating table with two vibrators that move in opposite directions on the tabletop, thereby generating a vertical vibration. In contrast, conventional vibrating tables are equipped with a motor that produces a circular vibration.

The amplitude of the unbalance motors can be adjusted manually in incremental steps using clamping discs. The frequency and time are set on the associated control unit. The fixed locking unit for the sedimentation cylinder, in accordance with the SVB guideline of the DAfStb, is situated between the two motors. At the centre of the cylinder, there is a plastic tube within which a radar tube probe is inserted. This can measure the moisture content before and after vibration by moving in the individual segments, thus enabling the determination of the segregation tendency based on the observed differences in moisture distribution between the segments.

Additionally, an acceleration sensor is affixed to the vibration table, which records meticulous data regarding the designated target frequency and the actual frequency. The acceleration sensor records acceleration in trialaxial planes. In the experiments described here, only the vertical direction is considered. To ascertain the amplitude, the acceleration sensor at the lower end of the vibrating plate is analysed, and a laser is attached to the upper part of the sedimentation cylinder to measure the amplitude in the y-direction.

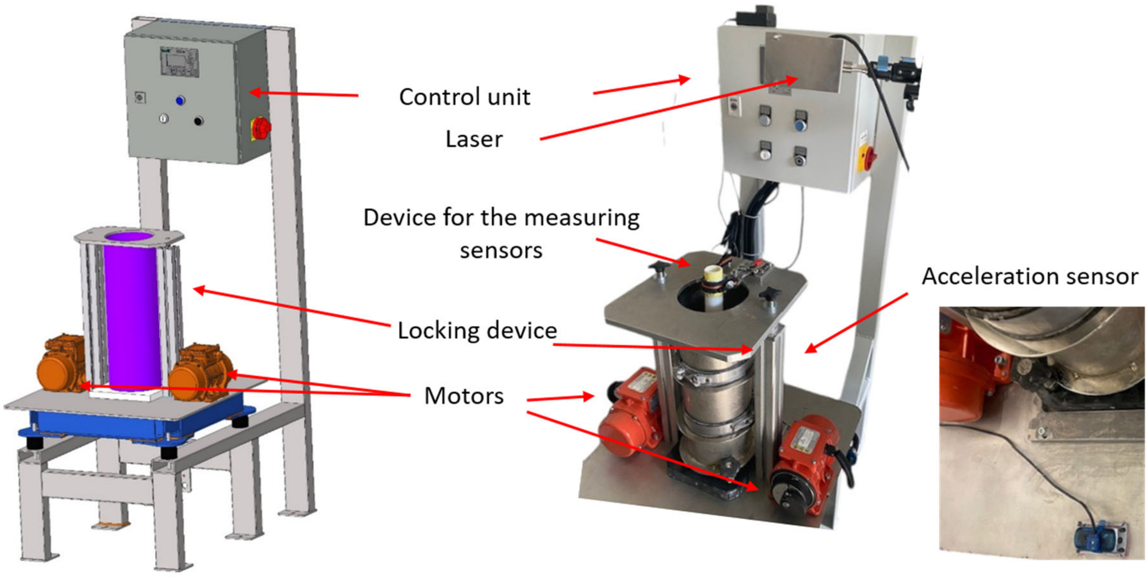

Fig. 1: Prototyp P-Typ 6

2. COMPACTING

During the vibration process, the yield stress of the concrete is reduced, resulting in a compaction of the material through the reduction of both cohesion and friction between the individual components [8]. This enables the particles to adhere in closer proximity to one another. The vibration causes the air bubbles to emerge and dissipate at the surface. The process results in enhanced strength and density. The intensity of compaction is dependent upon the parameters of time, frequency and amplitude, and ultimately results in the application of compaction energy [9]. The principle of compaction by a vibrating table is analogous to that of an external vibrator. To generate a clear vibration, two motors can be operated in opposite directions in a parallel arrangement, as illustrated in Fig. 2 on the right, below the table top. This method is referred to as optimum concrete compaction, as it produces a vertical vibration perpendicular to the table top [8].

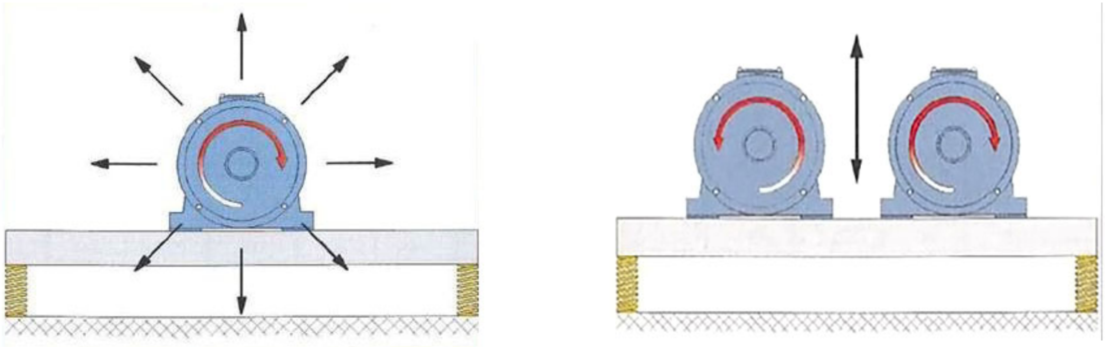

Fig. 2: Left unbalance motor as circular vibrator; right two unbalance motors, vertical compaction direction [8]

In order to enable transferability between the individual vibrating table designs, a translation of the compaction parameters into applied compaction energy is necessary and is calculated below according to Kirkham and White [10].

$$w_m = \frac{a_{max}^2}{16\pi^4 f} \left[\frac{J}{s} * kg\right] \tag{1}$$

Where:

w_m	is compacting energy,
a_{max}	is the maximum acceleration, and
f	is the frequency.

3. ACCELERATION MEASUREMENT

The vibrating table is suitable for both circular and vertical compaction. In the present study, only vertical compaction is considered. To this end, an acceleration sensor is affixed to the vibrating plate, which is capable of measuring acceleration in the x, y, and z directions. The motors of the vibrating plate can be adjusted via the unbalance discs, thereby exerting an influence on the amplitude. In this report, only the z-direction is considered. Initially, it was ascertained whether the target frequency set on the PLC corresponded to the actual frequency. To ensure the reproducibility of results, it is essential to record each individual parameter with precision. This allows for the scattering to be explained. The compaction energy can be employed as a measure for these variations.

Table 1 presents a summary of the findings from previous studies on the effects of vibration on concrete. The table compares the reported values for acceleration, amplitude (A), and direction of vibration. A comparison of the acceleration values documented in the literature with the values determined in this study reveals a discrepancy between the two sets of data. The measured accelerations of 5-7 m/s² are significantly lower than the documented values, while the amplitudes of 0.09-0.15 mm are approximately 58 % below the previously known values. This suggests that there may be differences in the test procedure or the devices used, which should be examined more closely in further analyses.

Table 1: Acceleration in vertical direction

Literature	**Accerleration [m/s²]**	**A [mm]**	**Vibration direction**
Spörel [7]	20-40	0.23-0.25	circular
Navarette [10]	50- 120	-	circular
P-Typ 5	20 -50	0.09-0.15	circular
P-Typ 6	5.4 – 7.9	0.05-0.15	vertical

The results shown in Table 2 demonstrate that the vibrating table was analysed in idle mode, with an unfilled cylinder and with a filled cylinder, at a compression time of 30 and 60 seconds. As part of the present study, the aforementioned scenarios were also analysed with an increase in unbalance (80 %). Depending on the load level, significantly different actual frequencies and different accelerations were recorded between the selected frequencies. The tests carried out demonstrate that the acceleration measurement at idle leads to an increase in the vibration amplitude, whereby this effect is particularly intensified when the unbalance is increased. At the factory setting, an acceleration of 5.4 to 7.9 m/s² was measured, while an acceleration of 6.7 to 26.4 m/s² was recorded when the position of the clamping disc was changed. The compaction scenarios with concrete resulted in a reduction in acceleration compared to the idle scenarios. This leads to the conclusion that the concrete absorbs the vibration energy. The compaction time has an influence on the acceleration, with longer compaction times tending to lead to higher values, especially with the increased imbalance.

Table 2: Results of varying scenarios on the vibrating table with factory setting and unbalance increase

Factory settings	**$a_{max,50\ Hz}$ [m/s²]**	**50 Hz**	**$a_{max,60\ Hz}$ [m/s²]**	**60 Hz**	**$a_{max,70\ Hz}$ [m/s²]**	**70 Hz**
Idle mode	6.3	50.0	6.5	55.0	6.9	74.0
With cylinder (empty)	6.3	50.0	7.7	58.0	5.7	39.0
With concrete 30s	5.8	38.0	5.9	42.0	6.8	56.0
With concrete 60s	5.4	42.0	6.0	48.0	7.9	46.0
Unbalance 80 %	**$a_{max,50\ Hz}$ [m/s²]**	**50 Hz**	**$a_{max,60\ Hz}$ [m/s²]**	**60 Hz**	**$a_{max,70\ Hz}$ [m/s²]**	**70 Hz**
Idle mode	6.7	47.0	8.5	63.0	14.1	65.0
With cylinder (empty)	16.6	78.0	26.5	68.0	26.4	67.0
With concrete 30s	6.0	46.0	12.5	74.0	-	-
With concrete 60s	9.7	66.0	14.0	57.0	-	-

4. RESULTS AND DISCUSSION

The following two diagrams in Fig. 3 demonstrate that the measured actual compaction work exhibits a strong correlation with the deviations of the determined fresh concrete densities from the washout test of the segments. This is evidenced by the correlation coefficient R², which equals 0.8853. This suggests that the actual data can be employed as a dependable indicator for characterising the compaction process and the subsequent sedimentation during the compaction interval. Conversely, Fig. 3 illustrates that no notable correlation can be established when utilising the target data, which exhibit a correlation coefficient R²= 0.6945.

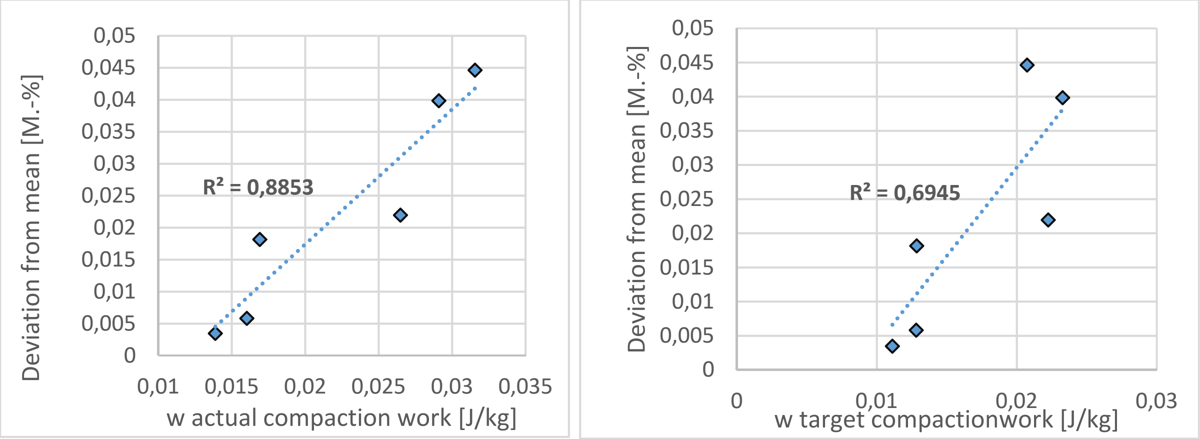

Fig. 3: Correlation between actual compaction work and the deviation of the fresh concrete densities of the individual segments in the three-cylinder washout test according to DAfStb and the target compaction work (right)

REFERENCES

[1] LOHAUS, L., HAIST, M., BEGEMANN, C.: *Stability of modern concrete: New approaches for testing and evaluation under vibration*, BFT International 2020 68–69

[2] DEUTSCHER AUSSCHUSS FÜR STAHLBETON E.V.: *Selbstverdichtender Beton: (SVB- Richtlinie)*, Beuth Verlag, Berlin, 2012

[3] LOWKE, D., SCHIEßL, P.: *Schnelltest zur Bestimmung der Sedimentationsneigung selbstverdichtender Betone: Grundlagen*, Versuchsbeschreibung und Ergebnisse von Laborversuchen, Beton (2007)

[4] BEGEMANN, C., COTARDO, D, LOHAUS, L.: *Mischungsstabilität fließfähiger Betone*, Bautechnik 95 (2018) 316–323, https://doi.org/10.1002/bate.201800017

[5] GEÇGEL, A. S., BAUMERT, C., GARRECHT, H.: *Sensor-based method for testing the sedimentation stability of modern concretes at construction sites,in research and in development*, CPI- Concrete Plant International (2020)

[6] GEÇGEL, A. S., BAUMERT, C., GARRECHT, H.: *New method for testing the sedimentation stability of modern concretes at construction sites*, IOP Conf. Ser.: Mater. Sci. Eng. 615 (2019) 12008. https://doi.org/10.1088/1757-899X/615/1/012008

[7] SPÖREL, F.: *Anwendung eines Prüfverfahrens zur Ermittlung der Sedimentationsstabilität von Rüttelbeton*, Weimar, 2018

[8] ZIMMER, U., REUTER, H.-H.: *Verdichten von Beton – Stand der modernen Laborrütteltischtechnik*, BFT International (2022)