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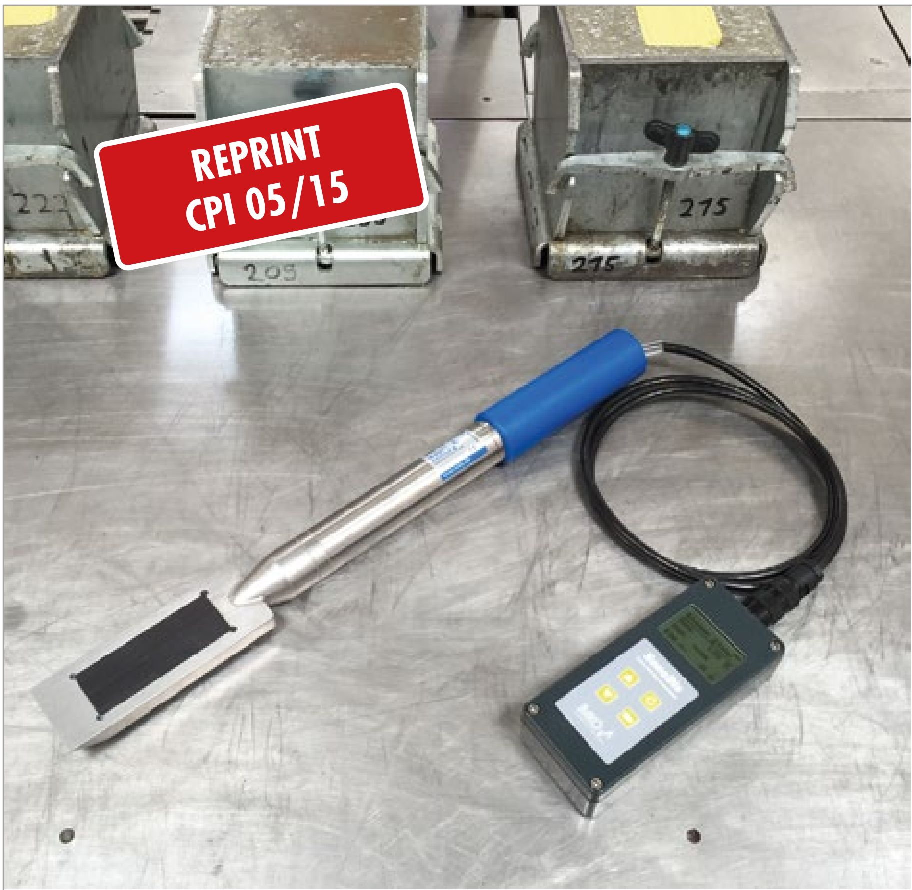

Determining fresh concrete water content rapidly by immersion probe

It frequently occurs in practical construction work that the actual water content in a construction component is found to be substantially more than the target water content. If this is noticed – mostly for reasons of poor strength – then the cause generally becomes a subject of dispute. Was the water content already too great on delivery or was the consistency raised with water by wish of the construction site above the consistency ordered? For example, if an F3 concrete has been ordered with a 54 cm target after pumping, it then is "enhanced" with water. This is obviously "recognisably too soft concrete", which the construction company is not permitted to install according to HGB § 377. In terms of water content, often only the water (intrinsic moisture + added water) is taken into consideration and the proportion of water from the admixture not recorded. However, the latter normally has to be taken into account with admixture content above 3 l/m³.
This paper is concerned with determining water content by means of radar impulse technology and will describe experience gained both from practice and from a laboratory test series. Advice on suitability in practice will be given and the limitations of this measurement method pointed out.

■ Dr. Jürgen Krell, krell-consult, Hilden, Germany ■

Technical consequences of excessive water content

Even adjusting concrete consistency by approx. 8-10 cm in flow spread by the non-permitted addition of water means that approximately 20 l/m³ (150 l / 7.5 m³ vehicle) more water is in the concrete.

The technical consequences of 20 l/m³ excessive water presence in the concrete for the usual C25/30 to C35/45 concretes are:

Their strength is substantially lowered

Loss of compressive strength approx. 8 N/mm²,

→ this means that the installed concrete is generally below $_{fck}$, the nominal strength

Their durability is substantially poorer

What is meant here is resistance against carbonation (protection of the reinforcement against corrosion), resistance against frost, chemical attack, etc.; this all becomes appreciably poorer. Reference works divide up the exposure classes with steps in water/cement values of 0.05; durability becomes one or two steps poorer by adding 20 l/m³ water.

→ this means reinforcement rusting, greater weathering with frost, less surface strength; possibly insufficient serviceability

Their shrinkage is substantially increased

Shrinkage increases by 0.15 – 0.20 mm/m, i.e. from e.g. 0.6 to 0.8 mm/m = +33%.

→ this means greater crack openings (crack width limitation), possibly with vertical cracks in the upper area and with floors/industrial floors more hairline cracks in the upper area

Their cohesive capacity is substantially worse

- **Bleeding**
  Bleeding mostly increases by more than the double. Usual amounts of bleed water are 5-8 l/m³.
  With the addition of an extra 20 l/m³, by the rule of thumb - "additional bleeding = approximately half the amount of extra water", - = + 10 l/m³, then taking 5-8 l/m³ to 15-18 l/m ³ = + 125 % to + 200 % increase in the amount of bleed water.
  → water runs, stronger outflows at leakage points and greater accumulation of fines in the upper area (see segregation)

- **Segregation**
  More fine grain and water accumulations occur on the construction component's upper side.
  → cracks in the component with fines/water accumulation; considerably more shrinkage, even far exceeding the above mentioned increases in shrinkage. This results in the following typical shrinkage patterns:
  - walls: vertical cracks in the upper walls
  - slabs: particularly well-defined hairline cracks in the upper area, surface dusting, poor adhesive tensile strength

Even if anybody involved in construction work should know all this, the well-known technical consequences of extra water content (due to the non-permitted addition of water) are consciously and happily ignored because a particularly soft consistency is preferred for installation.

Determining water content at a construction site

If the water content has been intentionally increased, nobody will be interested in determining any water content which is (known to be) excessive.

Kiln drying

Since the normal kiln drying [6] procedure for determining water content takes 30-45 min., and kiln drying using microwaves approximately 20-30 min., and, due to the usual stiffening process, nobody can wait that long before discharging, the results from kiln drying almost always arrive after the concrete has been installed. Then nobody wants to know that a "non-target specification" batch of concrete (as has just been evidenced) was installed not long ago.

Rapid testing / moisture probe

Determining the water content of fresh concrete is a very old subject. Amongst others, Nägele and Hilsdorf [1] remarked in 1980 that being able to rapidly determine water and cement content was helpful in monitoring concrete quality. At that time, everybody was talking about the Rapid Analysis Machine (RAM) from the USA. This expensive machine costing approximately DEM 60,000 was too large and the 10 minute measurement time was quite a long as well. It did not survive its testing phase in numer-

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His special achievements include applying his 36 years of experience to project monitoring, damage prevention, refurbishment, preparation of expert assessments, mediation plus consulting and training based on practice; his hallmark is the interface between the law and technology.

ous companies and research institutions because of "results too late", "too expensive" and "complicated prior information necessary for the concrete" in particular.

Measurement technology has, of course, become better and quicker over the last few years not least due to computing units which are smaller and less expensive now.

As regards measuring moisture with rocks, neutron probes [1], and later capacitive probes and microwave probes [2], are well-known from earlier; just lately the method using radar impulse technology has proved to be robust and reliable [3, 4].

This radar impulse technology method has also now been utilised with manual probes, which can be immersed in bulk solids for measuring moisture in aggregates. Since 2012, advances in development at Imko have produced a probe [5], which measures the water content of fresh concrete. Now, after several updates in the software and testing as to how to handle the probe properly, I view this probe as well suited for estimating water content in fresh concrete. Its accuracy is ± 5 l/m³ in comparison with kiln drying with individual values up to ±10 l/m³; it is unclear if the deviations are caused by an "imprecise kiln drying value" or by the probe.

Its accuracy depends on these preset values:

- Bulk density of the fresh concrete, since moisture is measured based on volume and must be converted to kg/m³.
- Distribution curve and maximum particle size, since it appears that an accumulation of more fine mortar in the interstices of the aggregates simulates greater water content.
- G Set: corrective value for admixture content and the proportion of core moisture in the rock as "core moisture in l/m³ divided by 3", a figure based on the manufacturer's experience.

Short error analysis

Bulk density

Any error in bulk density is reflected 1:1 e.g. it is set at 2,350 kg/dm³ as opposed to an actual value of 2,310 kg/dm³ → 2 % error in water content giving 188 l/m³ with 8 Vol.-% of water instead of 185 l/m³, the actual value. This "error" is minor so that it is enough to enter the fresh concrete bulk density value from the mix computation and not the actual one in this case.

(Please note that this statement is only primarily valid for normal concrete without any significant air void content. With greater air void content, e.g. with air-entrained concrete, I only have indicative measurements; it seems that the measurement results are somewhat too high.)

Distribution curve and maximum particle size

The distribution curve and maximum particle size should be selected appropriately. If AB 16 were selected although C8 is specified, the water content would have been underestimated by 15 l/m³ or else exceeded by 15 l/m³ if A32 were specified. The deviations are considerable and, for that reason, the appropriate input is crucial. The concrete manufacturer can be asked about the distribution curve area (mostly AB); the maximum particle size is to be found on the delivery note.

G Set

This is an across-the-board possibility of correction for adjusting the device to each type of concrete if this should be necessary. The manufacturer recommends that one fraction of core moisture (mostly 1/3 of the core moisture) be entered as a corrective value. This has been found to be workable in practice. A figure for the core moisture based on experience with regional rocks is sufficient as an input value.
In addition, the amount of admixture can be set as a corrective value at this point in order to display a measured value with the water content (made up of intrinsic moisture rock + added water but without admixture) usually given in the mixture computation.
If a concrete is to undergo monitoring, the settings for this concrete have to be carried out once; afterwards the concrete can be measured without further adjustments to these settings.

Handling the device

Within the context of a project about concrete bleeding at the VDZ (Verein Deutscher Zementwerke e.V., German Cement Works Association), I measured concretes produced in the laboratory with the device, since the true water content was available for these concretes as they had been processed with rocks whose surfaces were dry.
Concrete of an F3-F4 consistency was measured in a plastic bucket; differing immersion possibilities were tested in order to attain a reproducible value.

Figs.1,2: Carrying out the measuring procedure using the Sono WZ (radar impulse technology) with a fresh concrete sample

The measuring sensor has to be completely immersed in the concrete and be entirely covered with concrete (without air voids) so that a reproducible value can be attained. This is achieved by inserting the measuring sensor in the bucket from the outside at the opposite edge and then by moving it in one motion – as in paddling – towards the inside and simultaneously slightly upwards (Figs 1 and 2).

The bucket is subsequently turned by approximately 20 cm (Fig.3) and the measurement repeated four times. The values measured should not deviate by more than ± 5 l/m³ from each other.

This works well with concretes that are at least reasonably plastic (flow spread ≥ 40 cm) and exhibit good cohesion.
In the case of zero slump concretes, air pockets often form on the measurement sensor. The values measured fluctuate highly for this reason and are generally less informative and serviceable.
Moistening the entire measuring area – without air inclusion – is also difficult with very sticky mixes (ultra-fines content ≥ 400 kg/m³ and water ≤ 165 kg/m³). In this case, a light backwards and forwards motion can expel the air from the measuring sensor. Air pockets give unusually low measurement readings. By pressing the "Delete single value" button, they are not taken into account in forming an average.
Fig. 4 illustrates one such concrete with 420 kg/m³ ultra-fines content and only 160 l/m³ water, which is extremely "sticky". Reproducible measurement values (individual values 156-165 l/m³) could be generated by submersing the sensor at an angle and moving it around. The average value from five measurements was found to be 162 l/m³, close to the target value of 160 l/m³. The following five batches (laboratory production with target = 160 l/m³) generated an average probe value in the region of ± 4 l/m³ from the targeted value.
In the case of concretes tending to segregate off water very strongly (exhibiting bleeding in the research project), the motion also seemed on occasion to accumulate water at the measuring sensor so that the values measured fluctuated strongly and tended to display too much water content. These concretes were already discharging bleed water visibly in the bucket during the measurement procedure. In this case, an additional plastic top and modified measurement procedure proved to be helpful. The measuring sensor was immersed in the concrete at the bucket's edge and moved with a paddling motion with the measuring side towards the bucket's centre.
With an AB 16 distribution curve, cement content between 300 - 350 kg/m³ and water content of 170 up to 190 l/m³, the average values from five measurements (turned 4 x 20 cm in the bucket) were a maximum of ± 5 l/m³ off from the total amount of water weighed.

Systematic measurements in a ready-mix concrete production facility

In the course of quality control, the water content of one type of concrete for a major construction site was monitored throughout one hot day from 5:30 until 21:30 hours in a ready-mix facility.

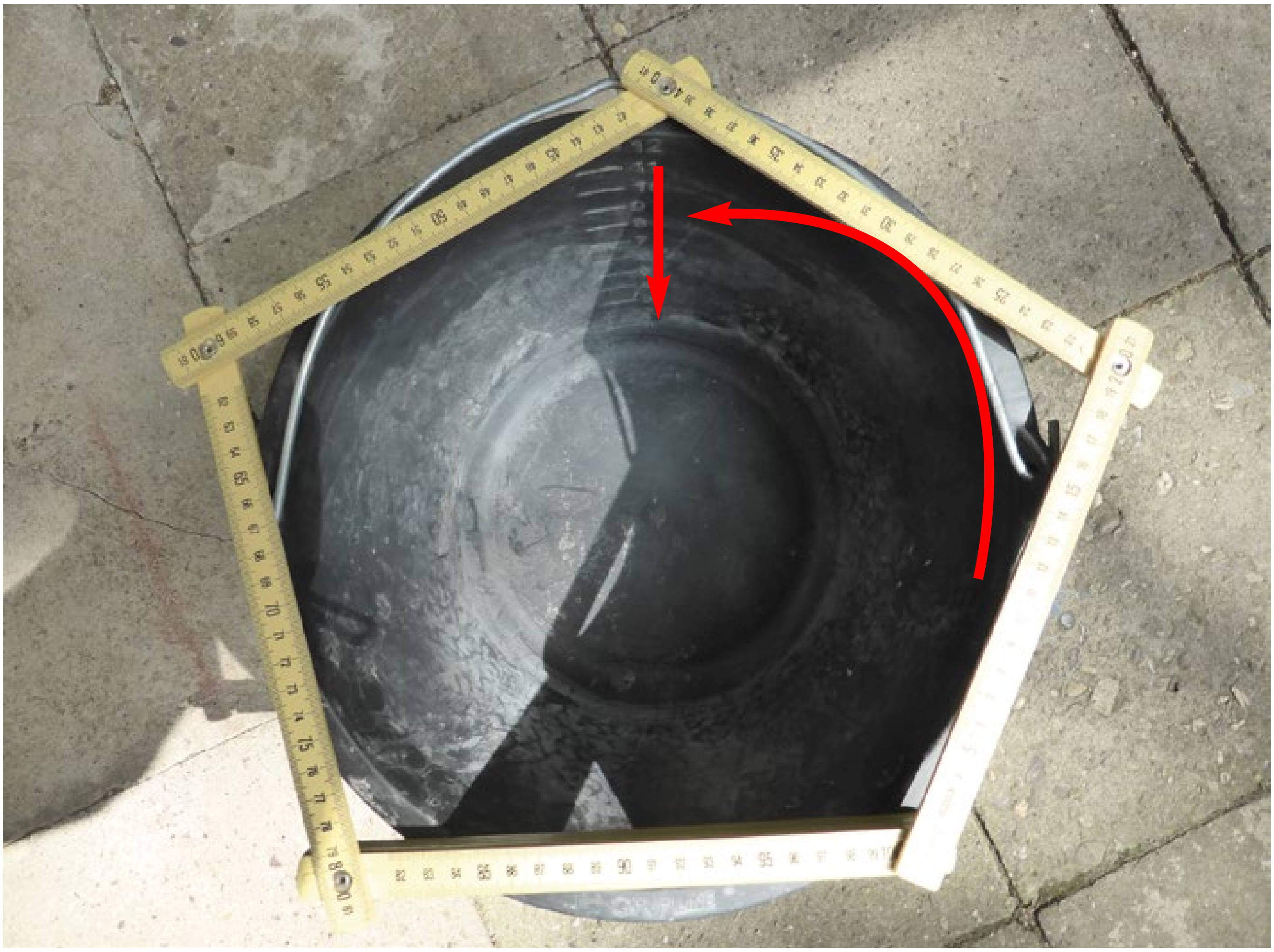

Fig. 3: Rotating the bucket by approx. 20 cm after taking each measurement

Fig. 4: Particular care must be taken that the measuring sensor is entirely moistened with concretes with great ultra-fine content or low water content.

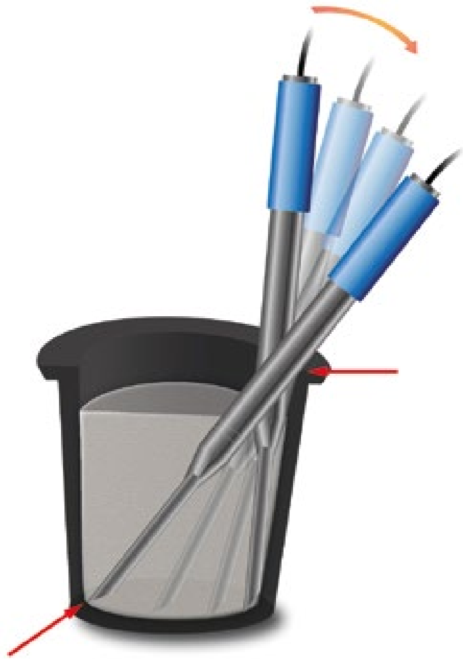

Fig. 5: Measuring procedure for concretes softer than F3

Tab. 1: Comparative measurements in a ready-mix concrete production facility

	Sono WZ probe [kg/m³]	Kiln drying [kg/m³]	Deviation [kg/m³]
	186	193	-7
	189	184	5
	205	205	0
	201	206	-5
	190	185	5
	195	191	4
	191	186	5
	188	187	1
Average:	193	192	

Tab. 2: comparative measurements bucket/wheelbarrow

Bucket [kg/m³]	Wheelbarrow [kg/m³]
195	196
191	190
188	190

(Target values: distribution curve AB 16: cement = 350 kg/m³, water = 175 l/m³)
42 measurements were taken with the Sono WZ probe with values from 168 to 205 l/m³. There was a pronounced tendency for higher values to be measured with the temperature of the fresh concretes above 26°C.

Eight values measured above 185 l/m³ were checked using kiln drying: this resulted in the following pairings (Core moisture = 0 setting)

This evaluation shows that, with 193 and 192 kg/m³, the average water contents were situated very closely to each other. The individual values scattered from -8 to + 5 kg/m³.

Three measurements were also carried out in a wheelbarrow by way of comparison, in order to avoid transferring into the bucket. Tab. 2 illustrates these comparative measurements. These show that the concrete does not have to be transferred to a bucket.

Fig. 6: Comparative measurements in a wheelbarrow

Table 3: Comparative measurements (Sono WZ in comparison with kiln-drying)

Sono WZ [kg/m³]	Kiln drying [kg/m³]	Difference [kg/m³]
203	208	-5
195	191	4
198	204	-6

Measurements in a precast component production facility

In this case, a report had been made concerning foundation components of 75 cm in height in which pronounced bleeding occurred at times. As bleeding essentially depends on the relationship of water/ultra-fines, two possibilities can be considered:

1) too much water
2) too little (or too coarse) fine grained materials, including cement, fly ash and the proportion of aggregates under 0.125 mm (sand and elutriable particles),

Measurements at the facility:
(Target values: distribution curve AB16: cement = 320 kg/m³, fines = 40 kg/m³, water = 175 kg/m³, ultra-fines from rock < 10 kg/m³)
32 measurements were taken with values measured for the water content from 169 to 189 kg/m³. Considerable bleeding occurred as expected with the five values measured above 183 kg/m³. One measured value was found to be 175 l/m³ but nonetheless considerable bleeding took place. In this case, an analysis of the batch records showed that the fly ash (40 kg/m³) had not been weighed in; this might probably have been the cause for bleeding in this case.

Use with a drilled pile wall

(Target values: distribution curve AB 32: cement = 350 kg/m³, fines = 50 kg/m³, water = 180 l/m³)

30 measurements were taken. The values measured lay between 178 and 215 kg/m³, of which five values were above 195 kg/m³. Above a value of 195 kg/m³, the concrete was not installed and one sample of the concrete was kiln dried.

As the comparative measurements had been shown to be successful, kiln drying was discontinued and measurements only taken with the probe.

Numerous individual measurements at differing construction sites provided evidence that anomalies with the probe in respect of too soft consistency or unusually strong bleeding – in comparison with the target values – originated (as expected) with increased water content.
Merely the fact that water content could be measured swiftly with the probe caused all participants (at least for the time the assessor was present) to make more effort in keeping as accurately as possible to the targeted water content. This applies both to the manufacturers and construction sites, who then, in the case of the F3 consistencies ordered, installed concretes in the lower permissible range of 43-45 cm flow spread without requesting the non-permitted addition of extra water.

Results

Up to the present time I have only measured systematic values in the F3 to F5 range for the predominantly utilised AB16 distribution curve with customary air content. The values give good reason for confidence that an accuracy of approximately ± 5 kg/m³, in comparison with target water, can be expected with these concretes. Too great water content seems to have been detected with air-entrained concrete.

Remarks

This measuring procedure does not function with steel fibres or metallic supplements, as the metal is evaluated as "water"! I have not yet made any investigations into concretes with composite fibres. In the case of concretes with silica slurry and great cement content, very high admixture contents of 5-7 kg/m³ are generally found. These must be taken into consideration in the G Set, since the value measured is usually compared with the given water content from the recipe (= moisture + added water without admixture).
The results show that exceeding the water content by any significant amount (> 10 l/m³) – with the above described negative technical consequences – will be recognised immediately!

As quality can only be produced and not achieved through testing, any concrete recognised as containing too much water must be disposed of, the reasons for the excess water content sought and eliminated by means of appropriate control measures.

Summary

The probe utilised here (Sono WZ from Imko) is a helpful tool for me as expert assessor for being able to rapidly recognise increased water content in concrete. It thus offers the possibility of being able to trace the reasons for this with a view to a targeted remedy. Secondary effect – when I turn up with the device at a production site or place of installation, a greater consciousness of quality and greater effort to achieve quality is immediately recognisable among the participants.

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