P-WAVE PROPAGATION IN SETTING AND HARDENING CONCRETE

P-WELLENFORTPFLANZUNG IN ERSTARRENDEM UND ERHÄRTENDEM BETON

PROPAGATION D'ONDES DE COMPRESSION DANS LE BETON PENDANT LA PRISE ET LE DURCISSEMENT

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SUMMARY

P-waves have been generated by an impacting steel ball on the container wall for fresh concrete. Measurements of the wave propagation velocity during the first 24 hours after concreting have been performed. The results show an influence of the water-cement ratio and of the paste volume on the velocity. The simultaneous retarding action of the superplasticizer used and the effect of the aggregate size appeared.

ZUSAMMENFASSUNG

Kompressionswellen wurden mit Hilfe einer Kugel erzeugt, die auf die Wand des Frischbetonbehälters auftraf. Messungen der Wellengeschwindigkeit wurden während der ersten 24 Stunden nach dem Betonieren ausgeführt. Die Ergebnisse zeigen den Einfluß des Wasserzementwerts und des Zementleimgehalts auf die Geschwindigkeit. Die gleichzeitige verzögernde Wirkung des verwendeten Fließmittels und der Effekt der Zuschlagsgröße konnten beobachtet werden.

RESUME

Les ondes de compression ont été générées par l'impact d'une bille d'acier sur la paroi du récipient pour le béton frais. Les métrages de la vélocité de propagation des ondes ont été effectués pendant les premières 24 heures après le bétonnage. Les résultats montrent l'influence du rapport eau-ciment et de la teneur en pâte de ciment sur la vélocité. L’effet retardateur simultané du superfluidifiant employé et l'influence de la taille des agrégats ont été observés.

KEYWORDS: concrete, setting, hardening, ultrasound, wave propagation, fresh concrete, P-wave

1 INTRODUCTION

In 1994, results on ultrasonic measurements on fresh and hardening concrete were reported [Grosse & Reinhardt 1994]. The variables of those tests were the water-cement ratio, the type of cement and the addition of retarders. It turned out that all variables had a specific influence on the propagation velocity of the compressional wave, on the transmitted energy, and on the frequency spectrum of the transmitted wave.

The investigations have now been extended to concretes with various water-cement ratios at the same paste content, with various aggregate sizes, a high-performance concrete and a self-compacting concrete. Furthermore, the testing device has been improved.

2 TEST SET-UP

An impacting steel ball with 4 mm diameter was used as wave generator. The ball was accelerated by compressed air and hit the PMMA container wall in the center with a velocity of about 11.2 m/s. The pulse had a duration of about 10 µs and a frequency range up to 100 kHz. The pulse was measured by a broadland piezo transducer which was mounted to the PMMA wall close to the point of impact. An equal broadland receiver was mounted to the opposite wall of the container for the transmitted signal. The clear distance from wall to wall was 70 mm. Both PMMA walls were clamped between coated plywood plates, but the contact between PMMA and plywood was very soft,due to a rubber sealant. By this measure, it was possible to suppress waves going through the walls faster than through the fresh concrete. Fig. 1 shows a scheme of the container. The signals were preamplified and recorded with a personal computer at a sampling rate of 5 MHz. Software for data processing able to evaluate the signals with respect to P-wave propagation velocity, transmitted energy and frequency content was available. However this paper is confined to wave propagation velocity.

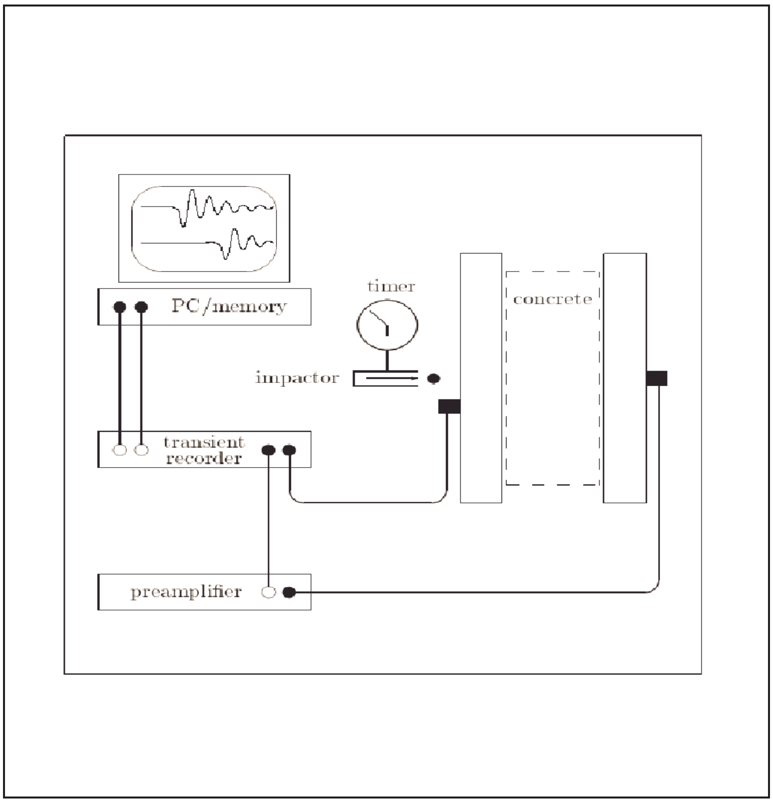

Fig. 1 Test set-up for US measurements on hardening concrete container.
Length = 160 mm, depth = 200 mm, width = 70 mm

3 CONCRETES TESTED

The reference mixture consisted of Portland cement CEM I 32.5 R, rounded natural quartzitic aggregates with 8 mm maximum aggregate size and a water-cement-ratio of 0.55. Keeping the paste content the same, the water-cement ratio was changed to 0.45 and 0.40. Then, the aggregate size was changed to 2 and 16 mm and the water-cement ratio was kept at 0.55. The paste content varied because workability should be approx. the same. Finally, a high-performance concrete and a self-compacting concrete were designed. Table 1 shows the mixtures. The paste content was calculated assuming the densities of cement and silica fume to be 3100 kg/m^3 and 2300 kg/m^3, resp.

Table 1. Mixtures tested

Component	Unit	Mixture code						
		55/8	45/8	40/8	55/2	55/16	33/8H	45/8F
Cement	kg/m^3	320	360	386	400	320	480	360
Water [1] -cement ratio	-	0.55	0.45	0.40	0.55	0.55	0.33	0.45
Max. aggregate size	mm	8	8	8	2	16	8	8
Silica fume [2]	kg/m^3	-	-	-	-	-	30	-
Superplasticizer	kg/m^3	-	-	-	-	-	13	5.4
Paste volume	l/m^3	279	278	279	349	279	339	283

[1] Water of silica slurry and superplasticizer included

[2] Dry mass

4 VELOCITY OF WAVE PROPAGATION

4.1 Results

The propagation velocity of the P-wave v_p is shown as function of concrete age in Figs. 2 to 4.

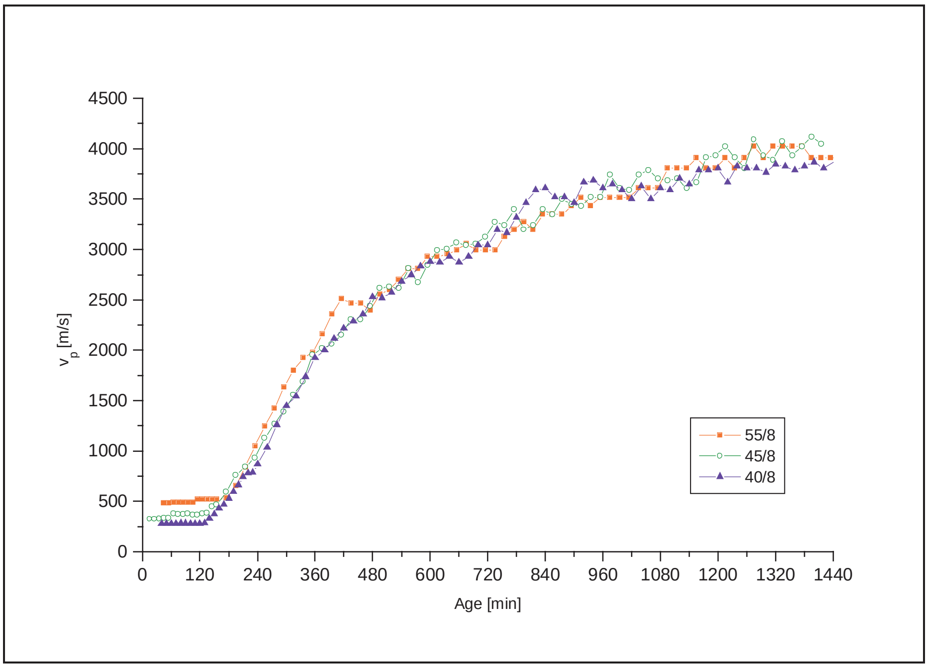

Fig. 2 Velocity of P-wave vs. concrete age and different water-cement ratios

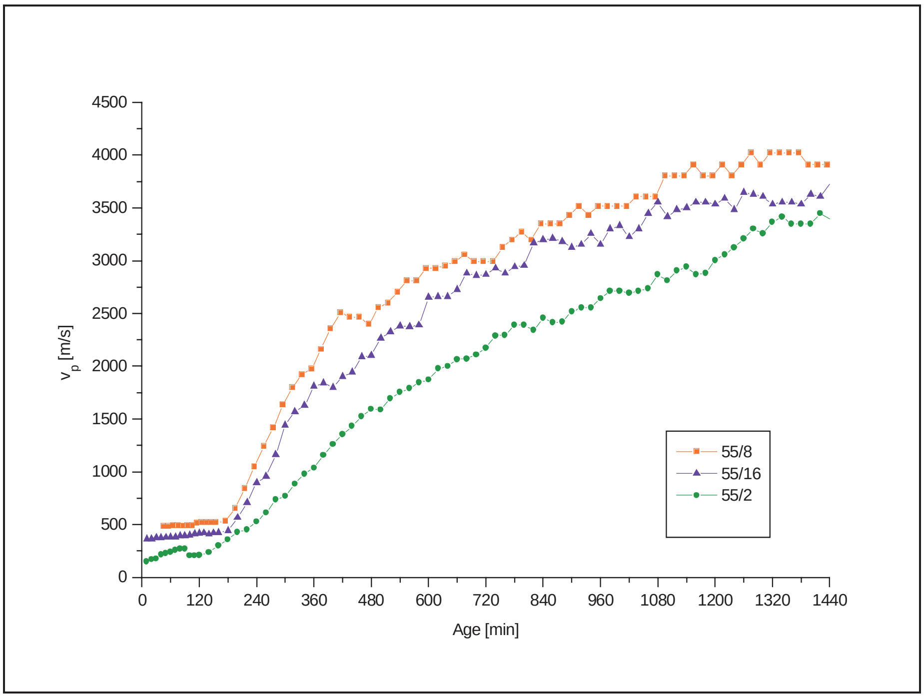

Fig. 3 Velocity of P-wave vs. concrete age and varying aggregate size

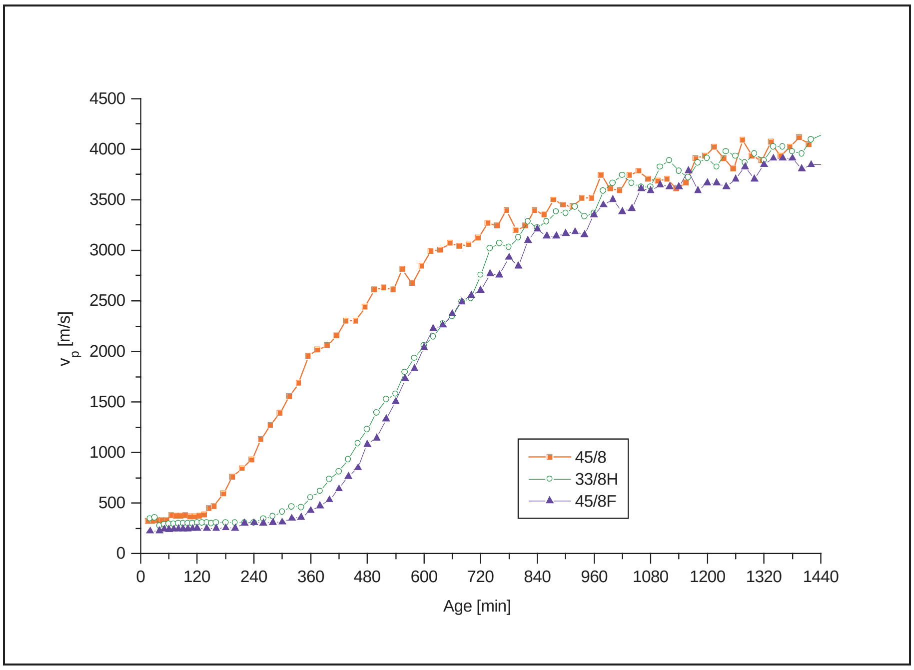

Fig. 4 Velocity of P-wave vs. concrete age for three mixes

The development of the P-wave velocity follows the same pattern as already reported [van der Winden, 1990; Grosse & Reinhardt, 1994; Reinhardt & Grosse, 1996]. During the fresh concrete state, the velocities are rather low and amount to 250 to 500 m/s. These velocities are considerably lower than the velocity of sound in water, which is about 1400 m/s. L´Hermite [l´Hermite, 1955] has explained this phenomenon by assuming oscillations between the grains in the paste rather than wave propagation in a continuum. There is lower velocity in concrete with a low water-cement ratio (Fig. 2) and small aggregate size (Fig. 3). However, the concrete with 16 mm aggregate has a lower velocity in the beginning than that with 8 mm grain size.

The age with low velocity extends to 120 to 180 minutes for those concretes which do not contain superplasticizer. The lower the water-cement ratio, the shorter is the period with low wave velocity. This effect may be attributed to the shorter distance of cement particles in a paste with low water-cement ratio and the early development of calcium hydroxide and trisulfate, which may cause a weak contact between the particles. The high-performance and the self-compacting concrete show the low velocity period up to about 360 minutes. This is due to the retarding effect of the lignosulfonate superplasticizer.

Figs. 2 to 4 show a steep increase of the velocity after the first stage. Irrespective of the water-cement ratio, the velocity increases to about 2500 m/s almost directly proportionally to the concrete age. Thereafter, the increase is slower and reaches about 4000 m/s after 24 hours. A similar behaviour is shown by concrete with 8 and 16 mm aggregate size. The high-performance concrete and self-compacting concrete develop faster in the second stage and reach the normal concrete at the concrete age of 800 minutes. Opposite to all other concretes, the concrete with 2 mm aggregate size starts at the lowest velocity and develops rather smoothly from 2 to 22 hours. It always shows a lower velocity than other concretes.

4.2 Discussion

The earlier results [Grosse & Reinhardt, 1994] showed a clear dependence of P-wave velocity on water-cement ratio during the second stage, i.e. between 120 and 500 minutes. The lower the water-cement ratio the faster was the velocity development. Fig. 2 does not show such an influence. The difference between the two test series is that the series of 1994 had a variation of water-cement ratio and paste content whereas the 1996 series kept the paste content constant. The results of 1996 can be interpreted such that a lower paste content caused a quicker rise of the wave velocity.

This interpretation is consistent with Fig. 3, where the largest paste content (Mix 55/2) had a lower increase of velocity with age of concrete. Unfortunately, the aggregate size was changed as a second parameter which makes the proof less valid.

This means that a main parameter which governs the velocity development is the paste content, and the water-cement ratio is only a secondary one. With the same paste content, the larger aggregate size caused a lower velocity, which is consistent through the whole testing time.

The test results indicate that the velocity in the first stage (2 to 3 hours) is governed both by paste content and water-cement ratio. The lower the paste content is, the higher the velocity which follows from the 1994 experiments gets. And the lower the water-cement ratio is, the lower is the velocity. In order to get a quantitative relationship between these parameters there should be at least two more test series: one with constant water-cement ratio and varying paste content, and another one with constant paste content and varying aggregate size between 4 and 32 mm.

5 CONCLUSION

The tests have shown that the testing method is well suited for conducting wave propagation experiments on fresh and hardening concrete.

The results show that two stages of P-wave propagation development exist: a first stage up to about 3 hours with a low velocity. There, the velocity is lower for a low water-cement ratio and larger paste volume. A second stage follows up to about 9 hours, where the water-cement ratio does not show an effect but the paste volume does.

The retarding action of a superplasticizer on lignosulfonate basis has shown up very clearly.

6 ACKNOWLEDGEMENT

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