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BEHAVIOUR OF CONCRETE POURED UNDER BENTONITE SUSPENSIONS
COMPORTEMENT DU BETON COULE SOUS SUSPENSION DE BENTONITE

CH. VEDER, O. Professor, Dipl. Ing., Dr. Techn., Dr. H. C.
H. KIENBERGER, Dipl. Ing.
Technische Hochschule Graz, Austria.

SYNOPSIS

It is shown by means of laboratory tests that the strength properties of concrete poured into trenches under bentonite suspensions are equal to those of concrete poured into dry soil or under ground water.
The strength values of concrete fromout the trenches are up to 2o % higher than for test cubes made of the same concrete and treated according to DIN 1045.

INTRODUCTION

For the construction of diaphragm walls in open cut linings or tunnel walls a highly plastic concrete is being used and introduced, with the used of the fixed tremie pipe method, under the bentonite suspension filling the trench. Occasional misgivings of the building industry for insufficient concrete quality and a sometimes unsatisfactory strength of the test cubes induced investigations of concrete strength in the finished building. Compression tests on drill cores and tests with the ball-impact hammer within the structure showed a much higher strength than had been suggested by the test cubes.

KIND AND PURPOSE OF TESTS

Comparisons have been carried out on a series of laboratory tests, the results of which are available, according to two criteria:

1. Comparison of concrete properties on concrete specimens cut out of test cylinders: the cylinders were made by concreting a) in a earth-moist ("dry") sand-gravel mixture, b) in a water-saturated sandy gravel ("under ground water level"), and c) in a hollow space filled with bentonite suspension in a water-saturated sand-gravel mixture
2. Comparisons of the concrete properties on concrete specimens from the above-mentioned (item 1) cylinders with test cubes prepared at the same time in steel formwork and treated and tested according to DIN 1045.

I. Experimental setup

A container 16o cm by 16o cm in plan and 7o cm high was filled with a sand-gravel mixture representing the natural soil. The pore volume was about 25 %.In the middle of the container a cylindrical hollow space was spared out over the whole depth and secured by a steel tube. This hollow space was concreted with plastic cast concrete by a funnel, then the steel tube drawn and thus a contact established between concrete and surrounding gravel. In contrast to the reference cubes the test body was kept in moist condition until the strength test after 28 days. In test series A no ground water was present in the sandy gravel, the hollow space in the middle was empty before concreting. In test series B ground water was present, the hollow space in the middle was filled with it, and it was displaced while introducing the concrete. In test series C

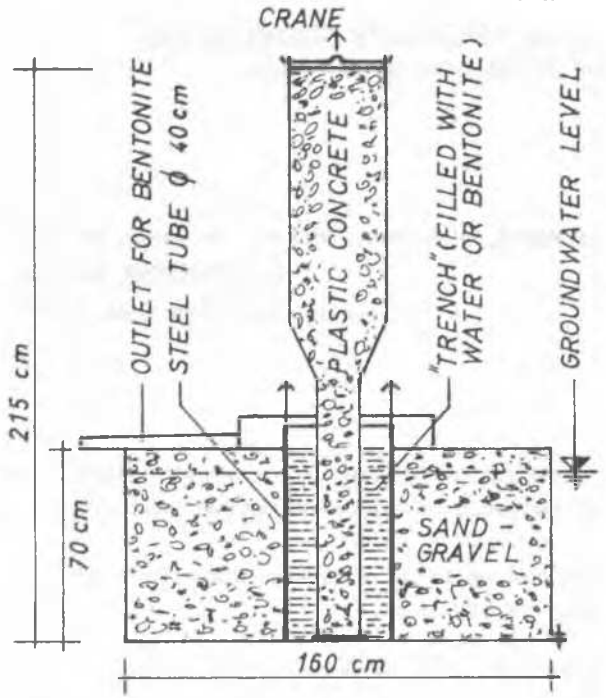

Fig. 1 Experimental setup

ground water was present, the cylindrical hollow space was filled with a 3% bentonite suspension. After drawing the steel tube the hollow space was concreted and the bentonite suspension displaced upwards.

II. Concrete properties

The aggregate used for the concrete was a sand-gravel mixture the grain size distribution of which is indicated in table I.

Table I : Sand-Gravel used for concrete

Grain size	cm	o,oo9	o,o2	o,1	o,3
weight	%	1,2	5,o	26,7	32,7
Grain size	cm	o,7	1,5	3,o	5,o
weihgt	%	53,4	78,8	97,6	1oo

The cement used was normal Portland cement PZ 275. The admixture was 350 Kp of cement to 1 cubic meter of finished concrete, the water-cement ratio, i.e. the relation between water and cement addition in weight, was o,60 for all tests, the volume weight of the unset concrete varied within the narrow limits of 2,38 to 2,41 tons per cubic meter and averaged 2,4o tons per cubic meter.

III. Sampling

For the strength tests of the bodies concreted into the gravel skeleton differently shaped samples were cut out of them after 28 days and subjected to a strength test. Cubes of 2o x 2o x 2o cm side length were used for the compressive strength tests, prisms of 12 x 12 x 36 cm for testing the tensile bending and cleavage strength and the modulus of elasticity, and plates 2o x 2o x 12 cm for testing the water penetration depth. The plates for the permeability tests were cut from the upper part of the cylinder, the cubes for the compressive strength tests from the lower portion.

IV. Reference cubes

Three reference cubes of 2o x 2o x 2o cm side length were made for each cylinder according to DIN 1045 from the same concrete as the test cylinders in moulds having smooth steel walls. In conformity to DIN 1045 the cubes were stored in moist condition for 7 days and afterwards in dry condition, and subjected to a compressive strength test after 28 days.

V. Test results

Three test cylinders and for each cylinder three reference cubes were made for each test series within which the test conditions were kept constant. As can be seen from Table II the values for the cube compressive strength, which are of primary interest, are distinctly higher for the cylinders than for the reference cubes obtained from steel forms, namely by +12 % for series A, + 10 % for series B and + 11 % for series C. Scattering within the series is in general under 3 %, max. 5 %. Conditions are similar for the tensile bending strength and the modulus of elasticity as can be seen from Table III. The difference in storing of the reference cubes and the test cylinders lead to another difference in strength that can be determi-

Table II : Comparison of series A B C

Series (Cond.)	Cyl No.	water -cem. ratio	slump cm	compressive strength (DIN 1045) 2ox2ox2o cm kp/cm²		compressive strength (cylinder) 2o/2o/2o cm kp/cm²		tensile bending strgth. (cylinder) 12/12/36 cm kp/cm²		modulus of elasticity (cylinder) 12/12/36 cm Mp/cm²		water penetration dpth (cylinder) 2o/2o/12 cm cm	
A	5	o,6o	61	249		27o		6o,2		244		8,6	
(dry)	6	o,6o	63	274	263	328	295	7o,4	64,5	252	247	9,2	9,1
	7	o,6o	6o	266		287		62,8		246		9,6	
B	2	o,6o	6o	254		267		64,2		239		9,1	
(grd.	3	o,6o	6o	267	26o	294	285	61,8	63,7	246	242	8,o	8,3
water)	4	o,6o	62	259		293		65,1		24o		7,9	
C	16	o,6o	58	276		3o1		63,8		255		7,4	
(ben-	17	o,6o	59	266	269	284	299	53,7	57,1	241	247	.	
ton.)	18	o,6o	6o	264		312		53,8		245		.	

Table III : Comparison of cylinders and cubes

		compressive strength kp/cm² series	mean	% deviat.	tensile bending strength kp/cm² series	mean	modulus of elasticity Mp/cm² series	mean	water penetration depth cm series	
Cubes	series A	263		-o,5	52,6		223		water penetr.	
	series B	26o	264	-1,5	57,3	56,8	229	223	per 12 cm at	
	series C	269		+2,o	6o,5		217		4,8 kp/cm²	
Cylinders	series A	295		+1,o	64,5		247		9,1	
	series B	285	293	-2,5	63,7	61,8	242	245	8,3	
	series C	299		+2,o	57,1		247		7,4	
increase in strength referring to test cubes			+ 11 %			+ 8,8%		+9,9%		
incr. in strength allowing for degree of curing			+ 2o %							

ned from Saul's rule as follows:
The degree of curing $R = a.(t + 1o)$ is the product of the hardening age a (expressed in days) and the sum $(t + 1o)$ where t is the temperature. For the reference cubes $R_w = 28.(2o + 1o) = 84o$ since storing was done at 20° C according to DIN 1045. For the test cylinders, however, the hardening was performed at the temperature of the circulating tap water (8 to 1o °C) so that $R_z = 28.(1o + 10) = 560$. In conformity with the relationship betwenn degree of curing (see fig. 2) and compressive strength (according to Price) the value corresponding to R_w of 98% of the compressive strength can be used as a reference value so that the value corresponding to R_z of 89% gives only 91% of the compressive strength of the cubes. Thus, the strength of the test cylinders might be 9% inferior to that of the refe-

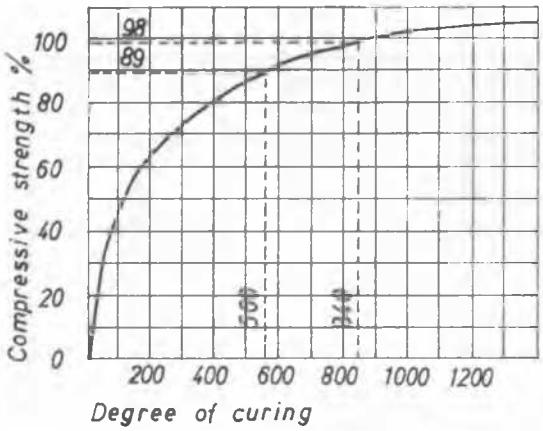

Fig. 2 : Relationship between compressive strength and degree of curing

rence cubes; however, it is 11 % higher on an average, which makes a total differrence of about 2o %.

CONCLUSION

This permits us to make two basic statements:

a. The strength properties of a plastic cast concrete introduced in a grain skeleton representing the natural soil are independent of the presence of ground water or a bentonite suspension in the trench. In this case the results only vary by -2,5 to +2,o % around the common mean value.

b. The strength properties of a plastic cast concrete introduced in a grain skeleton representing a natural soil are much better than those of the same concrete introduced, according to standard, in cube forms made of sheet steel, stored as prescribed and tested for strength. For the cubic compressive strength this difference after 28 days is 11 % on an average and, allowing for different degrees of curing, even up to 2o %. Conditions are similar for tensile bending strength, modulus of elasticity and water penetration depth.

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