Air Leakage Characteristics in Cracked Concrete

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1 INTRODUCTION

Under accidental loading beyond design limits, reinforced prestressed concrete containment vessels can fail by cracking which results from high internal pressure. Average widths and lengths of such cracks which develop in concrete membrane constructions as a result of tensile stresses can be calculated. These calculations allow the determination of the leakage area for the containment shell.

To date little work has been done on the topic of air leakage characteristics of cracked concrete. It is relatively unknown which amount of gas can flow through a cracked area per time unit. In most of the experimental work the crack width was confined to a range of 0.05 mm to 0.40 mm and the pressure gradient did not exceed 0.20 MPa (REFERENCES).

The German Ministry for Nature- and Environment-Protection and Reactor Safety is sponsoring currently a research program at the Universities of Kaiserslautern and Karlsruhe, with the aim of investigating the maximum strength of reinforced containment vessels in nuclear power plants. At the University of Kaiserslautern an experimental test program is realized with the objective of determining the air leakage rate through cracked concrete walls of different thicknesses. Through a leakage area, defined by an exactly measured crack pattern, the flow behavior will be investigated at very high overpressures, up to a maximum of 0.80 MPa.

2 TEST PROGRAM AND TEST SETUP

The test program includes two different test series. One is the basic research at a defined and well known single crack without any penetration of reinforcement, and the second series then considers a realistic crack pattern which will be influenced by different reinforcement arrangements.

2.1 Tests with a defined single crack

With a specially developed test specimen, shown in Fig. 1, the characteristic wall roughness coefficient can be determined in relation of the crack width, the aggregate grading curve and the type of aggregates used. The different test parameters are given in Table 1.

Fig. 1. Test specimen of Test No. 1.2.

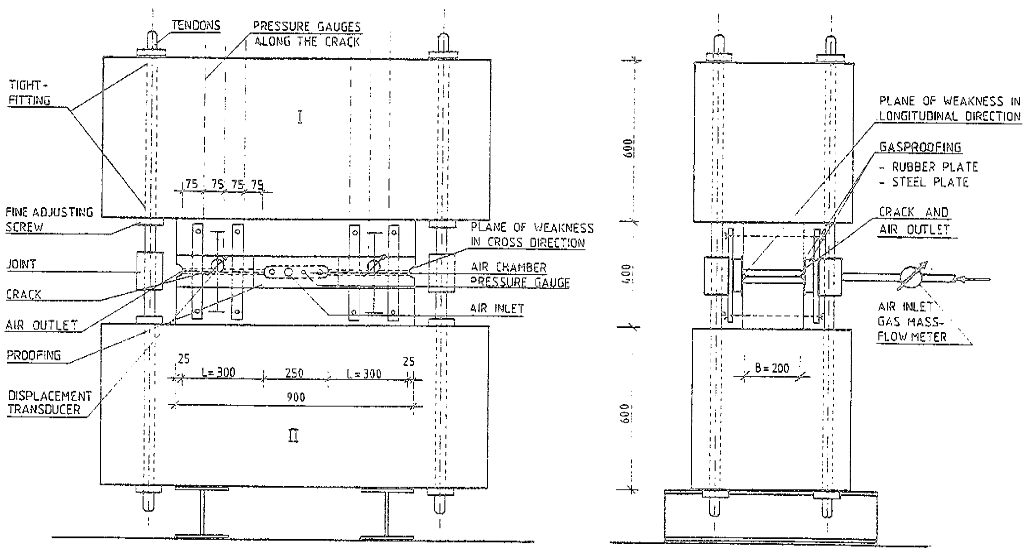


Table 1. Program for Tests with a defined single crack.

Test No.	Crack-length L	Type of concrete: Aggregate grading Curve	Type of concrete: Type of aggregate	Pressure gauges along the cracklength
1	300 mm	AB 16 *	sand, gravel	no
1.2	300 mm	AB 16	sand, gravel	yes
2	300 mm	AB 16	sand, chippings	no
3	300 mm	AB 8	sand, gravel	no
3.2	300 mm	AB 8	sand, gravel	yes
4	300 mm	AB 32	sand, gravel	no
5	150 mm	AB 16	sand, gravel	yes
6	450 mm	AB 16	sang, gravel	yes

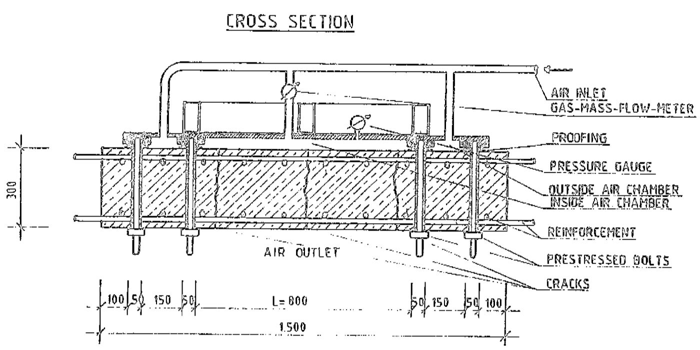
* denoted according to German Code DIN 1045 for a typical aggregate grading curve with 16 mm maximum aggregate size

In all tests the transverse extent of the crack is B = 200 mm. The crack width was varied in 0.10 mm steps from a beginning crack width of 0.20 mm or 0.30 mm to a maximum crack width of 1.30 mm. The gas used was compressed air.

2.2 Tests with a realistic crack-pattern

These tests were carried out to show the transferability of the results concerning characteristic wall roughness coefficients and air flow laws found in the tests with a single crack to a realistic crack pattern. Crack patterns caused under uniaxial und biaxial loadings were tested. Fig. 2 shows a test setup and in Table 2 the test program is specified.

Fig. 2. Test specimen of test No. 7.



The tensile forces to produce the crack patterns are applied via reinforcement bars which are tensioned externally to the specimen.

The reinforcement percentage was chosen with μ = 1.40 %, so using a reinforcement diameter of 20 mm, the calculated average crack distance will be 33 cm.

Under the planed loading the calculated average crack width will exceed 0.30 mm.

Table 2. Testing program for tests with a realistic. crack pattern

Test No.	Thicknes of plate	Form of crack pattern	Aggregate grading curve
7	300 mm	uniaxial	AB 8 *
8	300 mm	uniaxial	AB 16
9	300 mm	uniaxial	AB 32
10	300 mm	biaxial	AB 16

* Type of aggregate for all tests is sand and gravel

3 TESTING METHOD

3.1 Tests with a single crack

Before cracking, four displacement transducers were installed between the two abutments I and II and across the longiditunal direction of the crack. The crack was produced by using two hydraulic presses which were placed in between the abutments. After cracking the crack was held at a minimum opening of 0.20 mm or 0.30 mm by four tendons. For the different tests the intended crack width was adjusted in 0.10 mm steps by using fine adjustment screws.

During each test the overpressure at the air inlet was increased from a minimum of 0.10 MPa to a maximum pressure of 0.80 MPa in steps of 0.10 MPa. In contrast to earlier tests, given in literature, the measurement of the air flow was placed before the air inlet. Two gas mass-flow meters for different ranges were used for the gas flow measurements. This way of measurement is favourable, because it is independent of the gas pressure and temperature.

Two pressure gauges and four temperature elements were placed in the air chamber. In some tests the gas pressure gradient of longiditunal direction of the crack was measured. For this purpose, pressure gauges were installed along the crack.

3.2 Tests with a realistic crack-pattern

These tests are currently in preparation. Because of the difficult realisation of the gas proofing at the edges of the specimens and at the reinforcement penetrations at the sides, a special method for proofing along the sides were developed. It was aimed to get a vertical and direct flow of the air from the inner air chamber to the outlet. For this reason a second air chamber was installed around of the inner chamber. The applied pressure in this chamber was the same as in the inner chamber. This air flow enforced because of its backpressure a vertical air flow in the central. The gas flow is only measured in the inner air chamber which has a top side area of 0.80 m * 0.80 m. In this area three cracks can be expected due to a reinforcement percentage of $\mu = 1.40$ %. With four displacement transducers on each side of the plate the sum of the crack widths in both mean directions will be measured.

After cracking and installing the upper gas proofing gas - up to a maximum pressure of 0.50 MPa - will be pressed through the cracks, which can be opened step by step to a maximum single crack width of 0.50 mm.

As mentioned above, these tests are neccessary for transfering the results concerning wall roughness coefficients, obtained from tests with a single crack, to a realistic multiple crack-pattern. Another purpose is to get an idea of the influence which the reinforcement has on the air leakage rate.

4 RESULTS

In comparison with the flow-rate-formula, set up by Rizkalla, (Rizkalla et al. 1984) the tests with single cracks show principally the same flow behavior. But the test results found in the tests in Kaiserslautern were almost three times higher than the calculated leakage rate from the Rizkalla-formula. The Rizkalla flow-rate formula was developed by the theorem of momentum under the assumption of equal temperature in the air flow. The wall roughness coefficient and the flow coefficient in this formula were found by experiment.

At the moment investigations are under way to find out the reasons for the relative large difference between our test results and the flow prediction of Rizkalla. Through these investigations we are attempting to find new roughness and flow coefficients which fit also for high pressures up to 0.80 MPa and large crack widths of up to 1.30 mm.

The tests showed that the roughness coefficient is primarily dependent on the maximum size of aggregate used. On the other hand different types of aggregates, such as gravel or chippings, have practically no influence on the flow behavior through cracked concrete.

In Fig. 3 the results of test 1.2 are shown by way of example. The crack width W is plotted on the abscissa and the leakage rate Q on the ordinate. The pressure gradient p is taken as the curve parameter.

In Fig. 4 the pressure developement is plotted against the crack length for an adjusted crack width of 0.30 mm. A comparison with the curve bands of other crack widths shows an identical pressure development along the crack length.

Fig. 3. Test results of test 1.2.

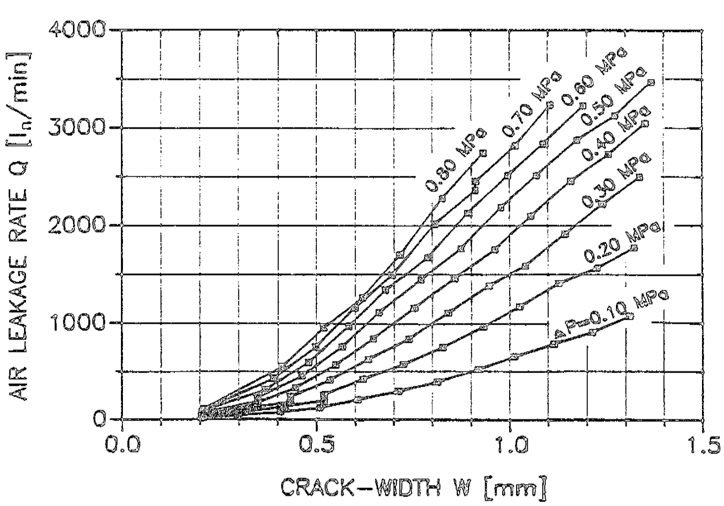
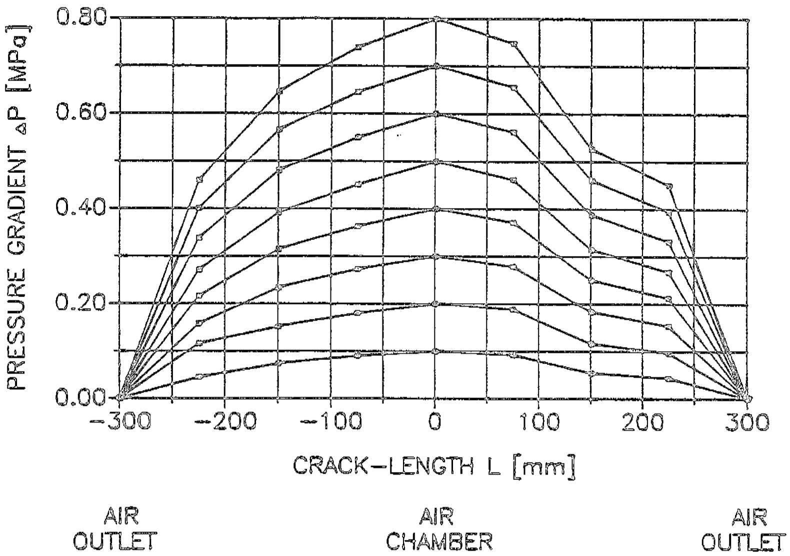


Fig. 4. Pressure gradient along the crack length.



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