AIR LEAKAGE THROUGH CRACKS IN CONCRETE ELEMENTS

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SYNOPSIS

The problem of air leakage through cracks in concrete elements is presented. Tests are reviewed and their results are discussed. Equations for determining the airflows through cracks are suggested. Finally, a comparison between the demands of Swedish building codes and the results of this investigation is made.

Key words: Air leakage, tightness of buildings, concrete element, cracks.

1. INTRODUCTION

A desired restraint of energy use in buildings makes demands upon the tightness of the house envelope. Swedish Building Code /1/ gives the maximum values of allowed ventilation rates in buildings. Concerning building components maximum values are given without further statements of the construction of the component. The building material concrete is applicable for wall constructions in one-family houses as well as in blocks of flats, at which air exchange at normal pressure differences between the inner and the exterior side of the wall occurs only through cracks in the concrete material (windows etc. are disregarded here). Of great interest is therefore the knowledge of leakage rates through cracks in concrete structures. The problem of air tightness is of great interest also in other concrete structures, such as tanks, shelters etc. This investigation deals partly with leakage through cracks in concrete elements, partly with cracks in joints between concrete elements.

2. EARLIER INVESTIGATIONS CONCERNING AIR LEAKAGE THROUGH CRACKS, SLOTS AND DUCTS

Studies of air leakage through cracks in concrete constructions are few. Ertingshausen & Steinert /2/ have investigated gas tightness in reinforced concrete plates for pressure differences >800 Pa, which is considerably more than test pressures used in this investigation.

Siitonen /3/ has studied untight joints between wood and concrete. At the Division of Structural Design, Chalmers University of Technology, air leakage through joints with gaskets has been investigated, Jergling /4/. Kronvall /5/ has studied air flows in building components experimentally as well as theoretically. Etheridge /6/ and Pihlajavaara /7/ have performed theoretical studies of air flows in cracks, and Esdorn & Rheinländer/8/ have studied air flows through ducts experimentally and theoretically.

3. EXPERIMENTAL INVESTIGATION

3.1 Test equipment and test methods

Determinations of air leakage dependence on pressure difference, crack width and crack depth have been carried out on laboratory-manufactured test specimens and on test specimens composed of parts from prefabricated concrete elements. The solid concrete specimens were made in the dimensions 300 x 500 mm and the different thicknesses 100, 150 and 200 mm, fig. 1. The prefabricated standard elements, grouted together with mortar, constituted test elements with thicknesses 150 and 265 mm, fig. 2 and 3. The magnitude of the air leakage at different pressure differences was determined for cracks through the concrete specimen and for cracks in joints between concrete elements. Measurements were made for crack widths 0.1, 0.3, 0.5 and 0.7 mm and pressure differences 25, 50, 75, 100, 300 and 500 Pa.

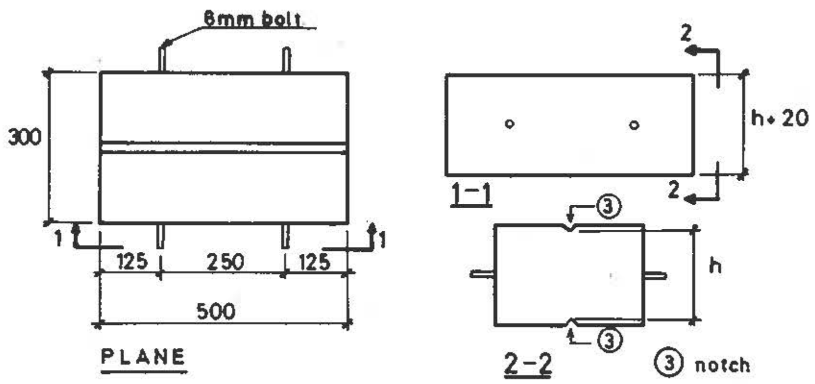


Fig. 1 Test specimen of solid concrete

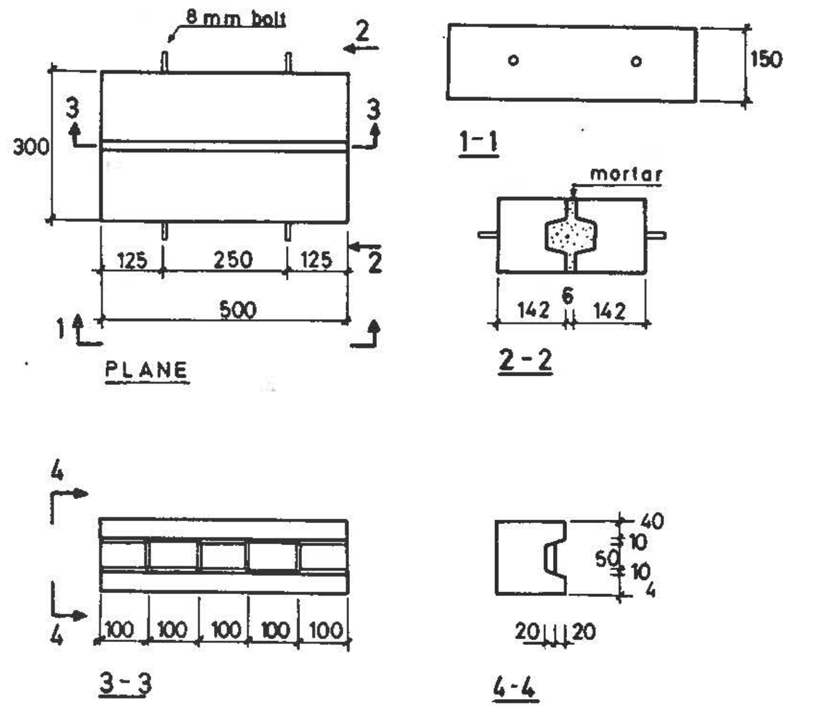


Fig. 2 Test specimen of prefabricated concrete element (wall components)

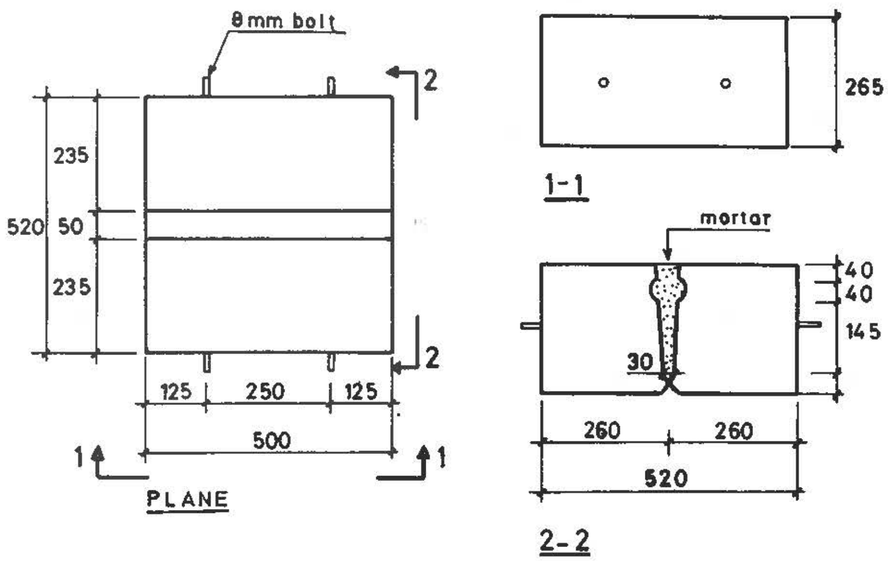
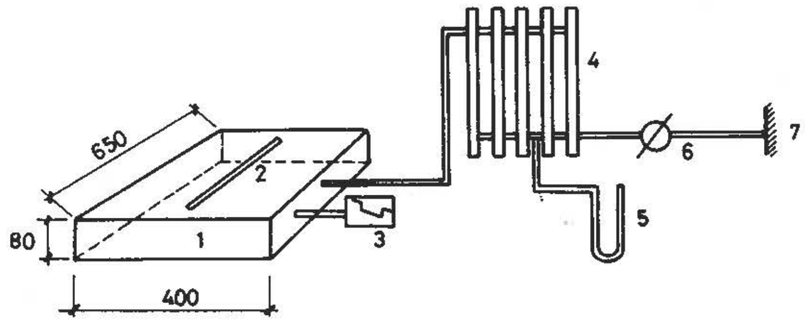


Fig. 3 Test specimen of prefabricated concrete element (floor components)

Cracking of the solid concrete element, fig. 1, was mainly performed according to the procedure at testing of tensile strength by pressing concrete cubes. Crack in the joint between mortar and concrete element was produced, after hardening, by means of pulling the test specimens' firmly fixed bolts.
In order to avoid cracks in the mortar, one side of the joint was coated with retarder before jointing.

The crack widths were controlled and determined by means of a deformation meter, type Staeger, and the variations in width were regulated by means of bolts fixed in the elements. The specimens were mounted on the top of an airtight box made of sheet steel, fig. 4, and air leakage rate, at different pressures, was determined by use of a flowmeter, type Rotameter. The inaccuracy of the test equipment has been estimated as <5%. The test results are given in 3.2.



(1) pressure box

(2) slot

(3) micromanometer

(4) flowmeter

(5) U-tube (manometer)

(6) pressure regulator

(7) connection with compressed air

(8) specimen

Fig. 4 Test equipment

3.2 Air leakage through cracks in solid concrete elements

Air leakage through cracks in solid concrete elements with thicknesses 100, 150 and 200 mm was determined according to the procedure described in section 3.1. In fig. 5 some of the test results are reviewed. For the remaining test results, see Jergling /9/.

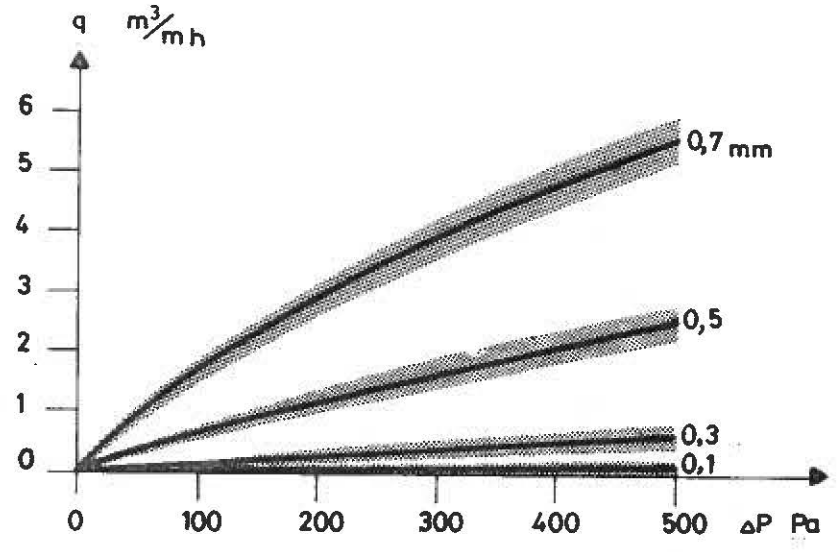


Fig. 5 Air-flow through cracks in 100 mm solid concrete elements, mean values for all measurements (hatching denotes 95% interval)

The variations of air leakage rates for different element thicknesses are illustrated in figs. 6 and 7. The relationships are non-linear. The presented figures show how, for instance, increased thickness in a concrete wall implies a modification in the air exchange rate.

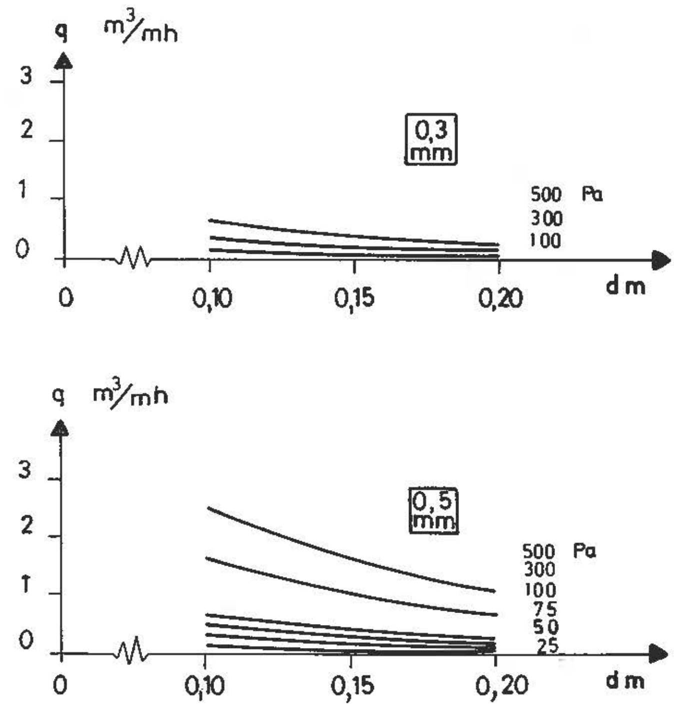


Fig. 6 Relationship between air leakage and element thickness for crack widths 0.3 and 0.5.

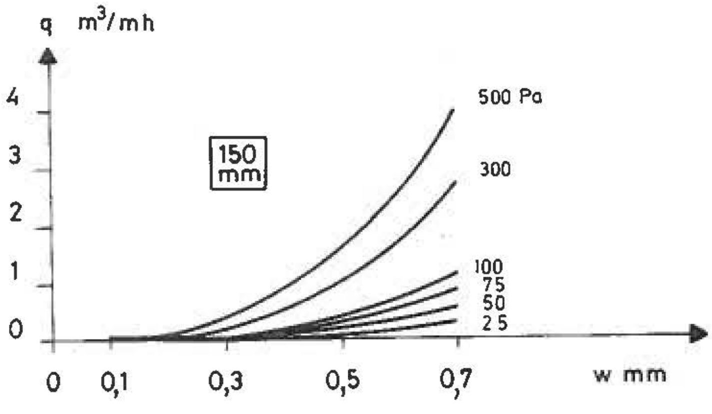


Fig. 7 Relationship between air leakage and crack width for element thickness 100 mm.

A comparison with other measurements, Esdorn & Rheinländer /8/, shows that air-flows through slots with completely smooth walls are appreciably greater (about 4-5 times).

In section 4.2 theoretically calculated values are compared with the experimental results and analytical expressions for air-flows through cracks in solid concrete elements are also stated.

3.3 Air leakage through cracks in joints between prefabricated concrete elements

Air leakage through cracks in joints between concrete elements was determined for both 150 mm wall elements and 265 mm floor components. Some of the test results for joints between wall elements are illustrated in fig. 8. For the remaining test results, see Jergling /9/.

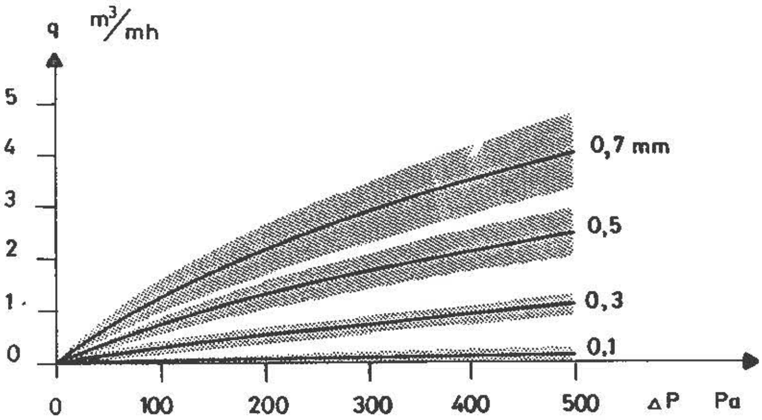


Fig. 8 Air-flow through cracks in mortar between 150 mm prefabricated concrete elements (hatching denotes 95% interval).

In section 4.3 theoretical calculations are compared with the experimental results and also stated are analytical expressions for air-flows through cracks in mortar between concrete elements.

4. ANALYTICAL DETERMINATION OF AIR-FLOWS THROUGH CRACKS

4.1 General expressions for the air-flow

The course of the flow through a concrete crack is complicated. A fictitious "tube of flow" has irregular shape and area, some parts of the boundary area touch upon concrete, some parts border more or less stationary air, fig. 9.

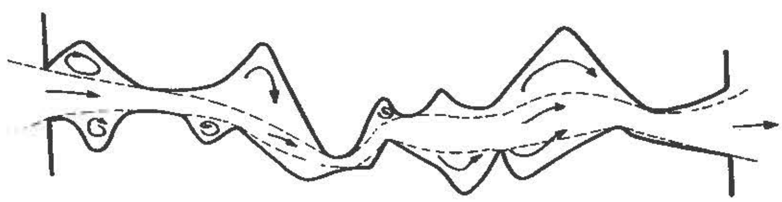


Fig. 9 Stream through a crack in concrete

Air-flow through a slot is often estimated by the simple expression

$$q = C_o(\Delta p)^n \ m^3/mh \qquad (4.11)$$

Eq. (4.11) is based on a rough picture of pressure conditions for air-flows through cracks.

The pressure difference across a crack is obtained from pressure losses at entrance and exit, which together with friction losses yield a relation of the form

$$\Delta p = \xi_1 \lambda \left(\frac{d}{w}\right)^m \frac{\rho v^2}{2} + \xi_2 \tfrac{1}{2}\rho v^2 \qquad (4.12)$$

where the first term corresponds to friction losses and the second to orifice losses. The loss factors ξ_1 and ξ_2 have been introduced because the tubes of flow have irregular shapes and the crack surfaces are very rough. The number of measurements in this investigation are not great enough to determine the roughness of different concrete cracks with a mathematical expression. Eq. (4.12) can be transformed into

$$\Delta p = A\frac{d}{w^3}\,q + B\frac{1}{w^2}\,q^2 \ \text{or} \ q = \frac{Ad}{2Bw}\left[\sqrt{1+\Delta p\frac{4Bw^4}{A^2d^2}} - 1\right] \qquad (4.13)$$

Calculations according to eq. (4.13) give approx. for air leakage through cracks in concrete

$$q = 14\ 10^6\frac{w^3}{d}\ \Delta p \ \text{for crack width} = 0.1\ 10^{-3}\text{m} \qquad (4.14a)$$

$$q = 0.010\frac{d}{w}k\left[\sqrt{1 + \Delta p\frac{w^4}{d^2}1.5\ 10^9} - 1\right] \qquad (4.14b)$$

for crack widths $0.3\ 10^{-3} \leq w \leq 0.7\ 10^{-3}$m ($q$ m^3/mh)

where k = 1 for d = 0.10 m
= 0.85 for d = 0.15 m
= 0.7 for d = 0.20 m

The equations (4.14) yield air-flows corresponding to the test values, fig. 10.

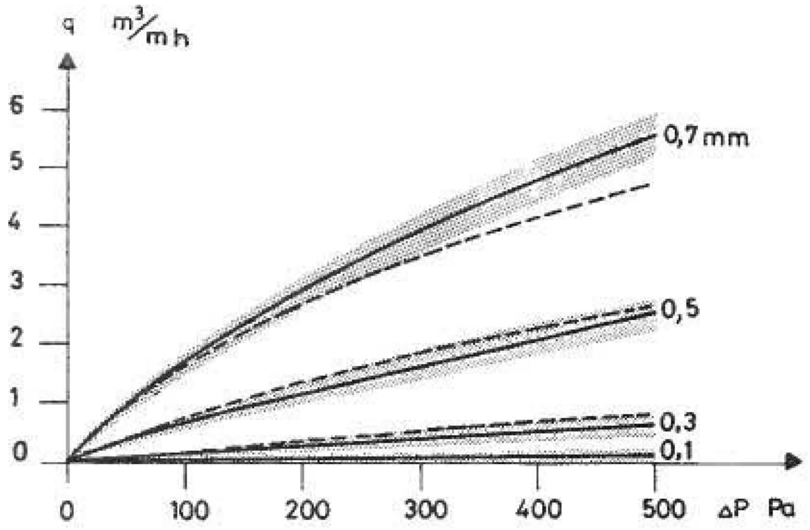


Fig. 10 Air-flows according to eq. (4.14) (dashed line) compared with test values (full line) for 100 mm concrete elements.

Eq. (4.11) gives n-values between 1.0 and 0.882 for cracks in concrete elements. For air leakage through joints between concrete elements eq. (4.13) gives

$$q = 10^{-3}\frac{k}{w}(\sqrt{1 + 220\ 10^{9}w^{4}\Delta p} - 1)\,m^{3}/mh \qquad (4.15)$$

for thickness 150 mm

where $k = 1$ for $w = 0.3 \cdot 10^{-3}m$
$k = 0.7$ for $0.5 \cdot 10^{-3} \leq w \leq 0.7 \cdot 10^{-3}m$ and

$$q = 0.71\ 10^{-3}\frac{1}{w}[\sqrt{1+0.1\ 10^{6}w^{4}\Delta p} - 1] \qquad (4.16)$$

for element thickness 265 mm and crack width $0.3 \cdot 10^{-3}m \leq w \leq 0.7\ 10^{-3}m$.

Eq. (4.15) and (4.16) fit the curves of test results with good accuracy. Eq. (4.11) gives n-values between 0.996 and 0.778 for element thickness 150 mm and 0.952 to 0.836 for 265 mm elements.

5. ESTIMATION OF CONCRETE STRUCTURES ACCORDING TO DEMANDS OF TIGHTNESS IN SWEDISH BUILDING CODES

According to Swedish Building Codes a building must have a satisfactory degree of air tightness. For buildings with ≥3 storeys the maximum air exchange rate is 0.2 m^3/m^2h for 50 Pa, which corresponds to 1.8 m^3/h for an assumed wall area of

3.6 x 2.5 m (normal wall area for a dwelling-room). Some examples of crack lengths corresponding to the tightness demand and calculated by means of the test results are presented in Table 1.

Table 1 Maximum crack length/outer wall area of a dwelling-room. Cracks through solid concrete.

Wall thickness m \ crack width mm	0.3	0.5	0.7
0.1	25	5	2
0.15	38	9	3
0.20	70	14	5

6. NOTATIONS

A,B = constants

C = constant

Re = Reynolds number

d = depth of section or a crack, m

k = constant

n,m = number, exponent, constant

p,Δp= pressure, Pa

q = air leakage, m^3/mh

v = velocity m/s

w = width of a crack

λ = friction factor = 96/Re

ρ = density kg/m^3

ξ = loss factor

7. REFERENCES

1. Svensk Byggnorm SBN 80 (Swedish Building Code 1980), Statens Planverk, Stockholm.

2. Ertingshausen H & Steinert J: Ergänzende Untersuchungen zur Gas- und Wasserdichtigkeit von Stahlbeton - Plattenstreifen, Lehrstuhl für Baukonstruktion und vorfertigung der Technische Universität Brauschweig, 1972.

3. Siitonen V: Investigation on the leak of untightened joints with laboratory tests. VTT, 1976, Finland.

4. Jergling A: Fogar mellan byggnadskomponenter i ytterväggar (Joints between building components in exterior walls). R 32:1979 BFR, Stockholm.

5. Kronvall J: Air flows in building components. Report TVBH 1002, Div. of Building Technology, Lund.

6. Etheridge D W: Crack flow equations and scale effect. Building and Environment, Vol. 12. 1977. London.

7. Pihlajavaara S: Air permeability of concrete and concrete structures VTT, 1979, Finland.

8. Esdorn H & Rheinländer J: Zur rechnerischen Ermittlung von Fugendurchlasskoefficienten und Druckexponenten für Bauteilfugen, Heizung-, Luft- und Haustechnik HLH 29 nr 3 1978, Berlin.

9. Jergling A: Air leakage through cracks in concrete elements. Report 1981:19. Division of Structural Design, Chalmers University of Technology, Sweden.