Water permeability and strength of concrete

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Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **13 (1988)**

PDF erstellt am: **11.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-12971

Water Permeability and Strength of Concrete

Perméabilité à l'eau et résistance du béton

Wasserdurchlässigkeit und Festigkeit des Betons

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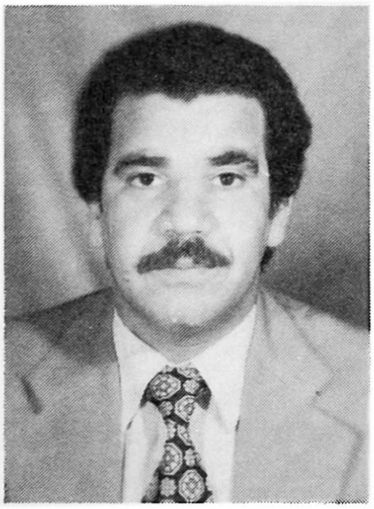

Ali Zregh born 1947 in Tripoli, B.Sc. MSCE and Ph.D. involved as a young engineer in design and construction of housing projects in Libya in the early 70's. Now as a staff member in Civil Engineering Dep. he is the Head of this department. He is a member in the local engineering societies and ACI, ASCE, SEA and others.

SUMMARY
Concrete is permeable when water can pass through its internal matrix under pressure. Permeability in concrete may be responsible for the disintegration of concrete. In this paper 30 different mixes were investigated. Variable water to cement ratios and cement contents were considered. Results and findings are reported at the end. A guideline to design a watertight concrete can be gained from this paper.

RÉSUMÉ
Le beton est considéré perméable lorsque l'eau sous pression peut pénétrer à travers sa matrice interne. La perméabilité du béton peut être á l'origine de sa désagrégation. Dans cette contribution, 30 différents mélanges de béton ont été considérés. Les paramètres variables ont été la rapport eau/ciment et la quantité de ciment contenue dans le mélange. Les résultats et les conclusions sont présentés, ainsi que des directives pour exécuter un béton imperméable.

ZUSAMMENFASSUNG
Beton ist durchlässig, wenn Wasser durch seine Zementmatrix dringen kann. Die Durchlässigkeit von Beton kann verantwortlich sein für dessen Zersetzung im Laufe der Zeit. In der beschriebenen Studie sind 30 verschiedene Betonmischungen untersucht worden. Die Versuchsparameter waren der Wasser/Zementfaktor und der Zementgehalt. Der Beitrag erläutert die Versuchsergebnisse und die Schlussfolgerungen. Es werden Richtlinien zur Herstellung eines wasserundurchlässigen Beton gegeben.

INTRODUCTION

Permeability is caused by existance of pores in the cement paste and the aggregate voids, because not all space between the aggregate particles becomes filled with solid cementations and fine materials. Furthermore to achieve a workable mix much more water is added than that required for the hydration of cement. Destruction of hardened concrete from freezing and thowing in presence of water, and corrosion of reinforcement subjected to moisture and air are problems related to the permeability of concrete. Burry and Domome [1] investigated penetration rates of sea water into concrete under pressure and concluded that penetration was found to be proportional to time to power 0.45. Datta in his ref. [2] concluded that if a relatively impermeable concrete is produced, the rate of chemical attack is drastically reduced thereby considerably delaying the rate of corrosion of reinforcement. Other researchers [3] and [4] indicated that the permeability of concrete is not a single function of its porosity but depends upon the size, shape and continuity of the pores and upon water to cement ratio. In this paper an attempt is made to investigate the behavior of concrete permeability with varying water to cement ratio and the cement content. Normal weight concrete with local "Libyan" materials were used. The materials properties are according to standards. Results and finding related to permeability and concrete strength are presented at end.

FACTORS AFFECTING PERMEABILITY OF CONCRETE

Three important factors may cause the concrete to be permeable:

1. The Constituent Materials:

   i - The fineness of cement improves the cohesiveness of mixes and hence the water tightness of concrete. It also controls the shrinkage and cracking. Cement with slow hydration and hardening characteristic tends to increase the permeability of concrete.

   ii - Water Cement Ratio:

   The permeability decreases as voids decreases but for plastic workable mixes the permeability increases as the water cement ratio increases as reported in ref. [1].

   iii - Aggregate and Cement:

   Both the cement paste and the aggregate contains pores that can permit liquid to pass through. Dense clean very well graded and fine grained aggregate yields a solid impermeable concrete. The greater the maximum size of aggregate for a given "W/C" water to cement ratio the greater the permeability as reported in ref. [2].

   iv - Admixtures:

   The main purpose of water proofing agents is to close the pores of the concrete matrix as lime soaps, butyle aluminium calcium or ammonium soaps, and also stearates or others.

2. Method of Preparation:

   Honey combing or differential settlements of newly placed fresh concrete can cause cracks. Workable, homogenous and well compacted concrete will minimize these defects.

3. Curing:

   If concrete is kept wet at early age the continued hydration of cement results in gel development which reduces the size of voids and increases the water tightness of concrete.

EXPERIMENTAL WORK:

All 30 mixes were designed according to the standards. Each of ingredients was compared to the ASTM specification. The cement properties met ASTM C150 while the aggregate met ASTM C33 and ASTM C-74. The 30 mixes were varied in both the cement content and water to cement ratio. Six cement contents were used starting from 2.45 KN/m^3 to 4.90 KN/m^3. That is at 0.49 KN/m^3 interval. At each case six water to cement ratios were varied starting from 0.45 to 0.70. Three mixes were omitted from both the lowest cement content and the highest cement content due to the workability problems. The aggregate to cement ratio was calculated for the 1st mix and found to be equal the value of 8.0 while in the last mix was found to be equal to the value of 3.25.

A total of 240 standards cubes "150 mm x 150 mm x 150 mm" were casted. Eight cubes for each mix were tested as follows: One cube per mix was tested for 3 days strength test, and one cube was tested for 7 days strength and 3 cubes were tested for 28 days strength. The last 3 cubes were tested for permeability test.

PERMEABILITY TEST:

Testing procedure was according DIN-1048. A constant pressure was applied to six specimens at each time. The water pressure was kept to 0.7 MPa. Percolation volume readings were taken at each half hour interval.

The coefficient of permeability K_c was determined from Darcy's law.

$$K_c = \frac{Q}{A} \times \frac{L}{H} \qquad (1)$$

Where

K_c = permeability coefficient m/sec.

Q = rate flow (m^3/sec)

A = cube cross-sectional area (0.15 m x 0.15 m)

L = specimen depth (0.15 m)*

H = water head above specimen (71.35 m)

Therefore equation (1) becomes:

$$K_c = 9.342^* \times 10^{-8}\ Q \quad m/sec. \qquad (2)$$

TEST RESULTS AND DISCUSSION:

Fig. 1 shows the 28 days compressive strength for the 30 different mixes versus the water to cement ratio and the cement content. As the "W/C" water to cement ratio increases the compressive strength decreases, and as the cement content decreases the compressive strength increases. This is due to the increase of aggregate to cement ratio.

A typical behavior of concrete permeability "water percolation rate to fill up voids" at 6 hours is shown in Fig. 2. As W/C increases the percolation rate increases for a constant cement content. The permeability increases as the cement content increases. Fig. 3 shows the same trend of permeability but at 24 hours. A combination of 30 min., 6 hours and 24 hours permeability coefficient "K_c" is illustrated for a constant cement content. K_c values are larger in the early stage since voids are to be filled first. It is important to notice that permeability does not mean leakage.

The lower the cement content the lower the K_c values are, and this is due to pores in the cement paste. This can be seen from Fig. 3 which illustrates also the permeable "leakage" and impermeable mixes. The lowest K_c value "0.76×10^{-4}" m/sec occured at the mix of which had W/C = 0.45 and cement content of 2.94 KN/m^3.

The same mix in Fig. 1 had the highest compressive strength which is equal to 46.1 MPa.

CONCLUSIONS AND RECOMMENDATIONS

1. A low value of cement content associated with a lower value of W/C yields both impermeable and high strength concrete, however trial mixes are recommended.
2. A value of $K_c = 4 \times 10^{-11}$ m/sec after 24 hours meant the concrete is impermeable under 0.7 MPa pressure.
3. Watertight concrete without any admixtures added does not exist because of the pores in both cement paste and aggregate particles.
4. More research is required on permeability and admixtures effect.

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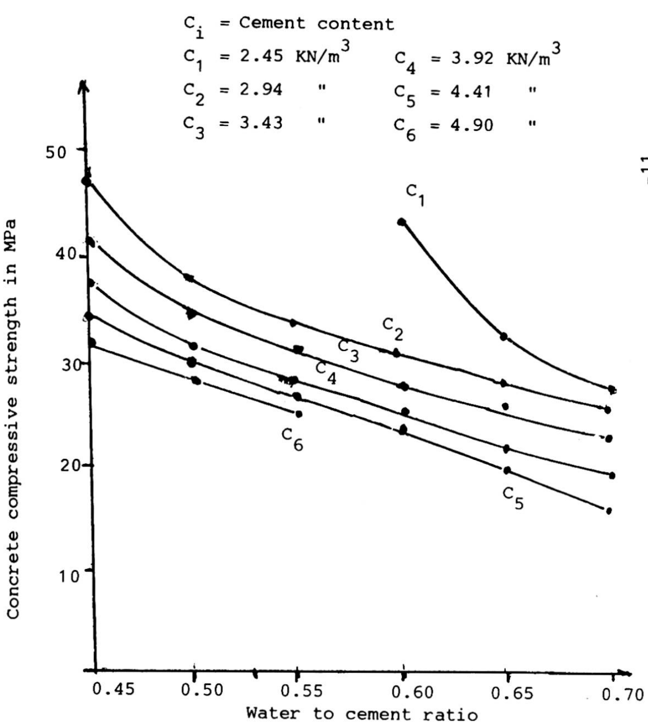

Fig. 1 : Cement content effect on concrete strength

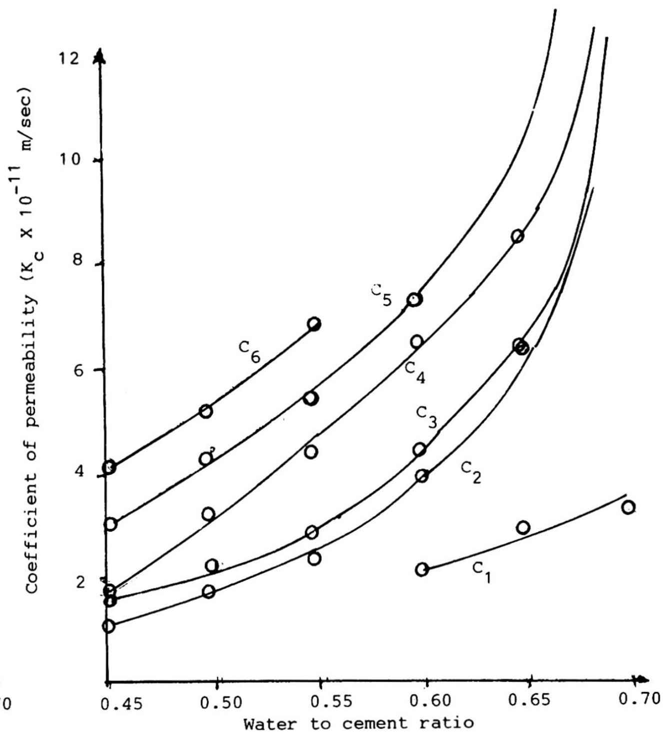

Fig. 2 : Cement content effect on permeability 6 hours test.

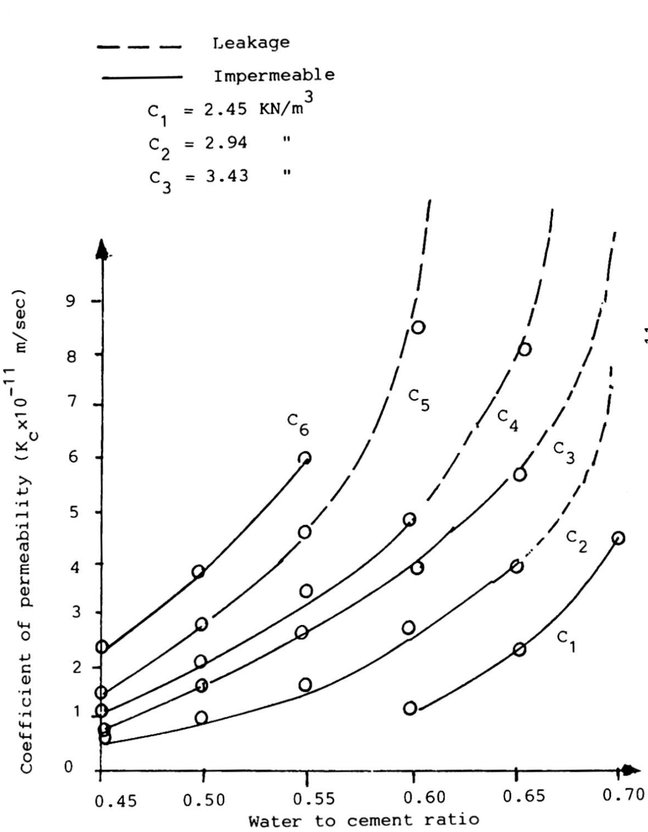

Fig. 3 Cement content effect on permeability 24 hours test.

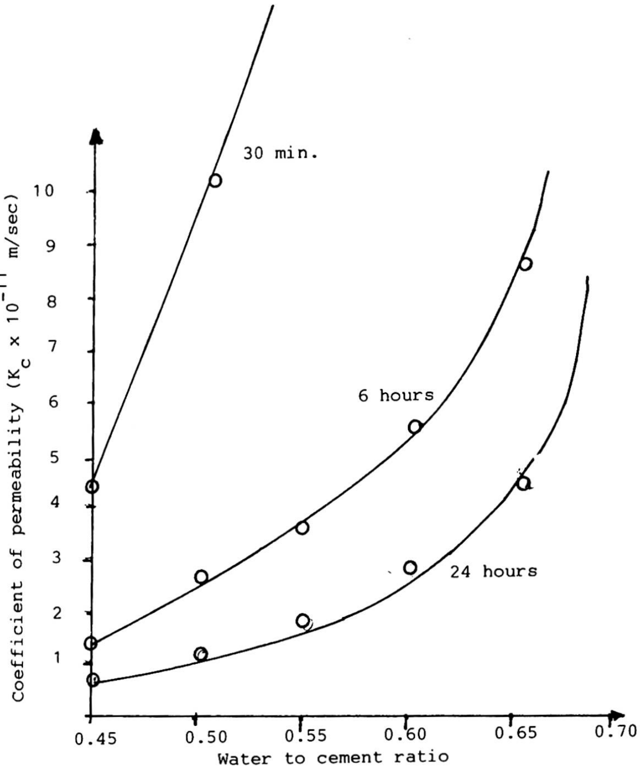

Fig. 4 Time effect on permeability for "C_2" cement content.