A DEVELOPED TECHNIQUE FOR IN-SITU TESTING FOR AIR PERMEABILITY

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ABSTRACT

The use of non-destructive tests has become part of the accepted quality control procedures in many countries. In-situ permeability techniques are also gaining wide recognition. However, local engineering practice is still to realize full potentialities of these methods. This work presents a non-destructive locally designed and manufactured portable inexpensive air permeability test apparatus: 'The Air Permeameter'. The technique is evaluated both in the laboratory and in-situ. The developed air permeability apparatus proved successful and sensitive to the variation of concrete mix parameters, curing conditions, and age of testing.

Key words

Non-destructive tests; In-situ testing; Permeability; Concrete.

INTRODUCTION

The use of concrete standard compressive strength test (150mm) for quality control is now a well established practice in Egypt. Unfortunately, this technique checks for the structural strength of buildings but gives only a vague idea about the durability of concrete in these buildings. Permeability, in this respect, is one of the most important properties in relation to durability of concrete. In particular, it gains an added importance in the design of water retaining structures and some parts of nuclear reactors. Structural members exposed to aggressive elements (e.g. de-icing salts, sea water, sulphates, or çhlorides) should also have low permeability to ensure their durability during service life.

Tests are available to estimate air and water permeability of concrete [1]. However, almost all permeability tests can not be applied in-situ successfully, because of the difficulties related to test setup and equipment portability. In Egypt, there is an added difficulty due to cost.

In general, in-situ quality control tests should be inexpensive to gain wide adoption. This work presents a new air permeability test using a simple, cheap, and portable apparatus. Results of experimentation with the developed apparatus, in both laboratory and field are outlined and analyzed. To this end, the rest of this work is organized as follows. First ,the available tests for in-situ permeation are briefed. Subsequent sections describe the developed 'Air Permeameter', the experimental program, results and discussion, and in-situ applications of the apparatus, respectively. Finally, conclusions are drawn.

IN-SITU PERMEATION TESTS

The available tests for in-situ permeation are summarized in the table below.

Test Name	Procedure	Disadvantages	Ref
Clam Sorptivity	The cumulative water absorbed ($m^3/\sqrt{min}$) through a test area of 50 mm diameter over a period of 15 minutes is determined. This gives the sorptivity index.	For the index to be correct, uni-directional flow should be established. This is not easy. In addition, the apparatus is expensive.	2
ISAT	The rate of flow of water ($ml/m^3/sec$) into concrete per unit area is measured after a certain interval of time and at a constant applied water head of 200 mm.	Difficult to achieve a good seal between the water head reservoir and the concrete surface. In addition, same difficulties with Clam test are encountered.	3
Figg Water Test	A specific volume of water is introduced into a sealed cavity using a hypodermic needle. The time needed for the water to be absorbed by capillarity is called Figg water permeability index.	The hypodermic needle can become clogged up with debri from the cavity. Moreover, the apparatus is expensive.	1
Figg Air Test	Air is drawn from a sealed cavity using a hand vacuum pump. The time in seconds for the pressure to recover from 55 to 50 KPa below atmospheric pressure is called Figg air permeability index.	The same as in Figg water permeability test.	1
Hong and Parrott Method	The time needed for the pressure to drop from 1000 to 950 kPa above atmospheric pressure in a sealed cavity is taken as the permeability index.	The apparatus includes an electric pump. This is expensive and difficult to transport to different sites.	4

THE DEVELOPED AIR PERMEABILITY TEST "THE AIR PERMEAMETER"

Test Apparatus

The developed test apparatus consists of a hand operated air compressor, a non-returnable valve to prevent compressed air form dissipating back through the fittings, and a pressure gauge (up to 10 kg/cm^2) to indicate the compressed air pressure. The pipes and fittings are made of copper; shaped and connected by welding. The test apparatus is shown in Fig. (1).

Test Procedure

A 13x50mm hole is drilled into the concrete test surface and then cleaned by blowing air. A steel insert 13x20 mm is fixed in the hole using a quick adhesive, left for about 15 minutes, and then tested. Air is pumped into the hole to a fixed pressure of 2.5 kg/cm^2. This pressure was found not aggressive for low strength concrete. The elapsed time for pressure to decay from 2.5 to 1.5 kg/cm^2 is considered as the impermeability index of concrete.

EXPERIMENTAL PROGRAM

The experimental program comprises two stages of work: laboratory testing of concrete cover and in-situ evaluation of the permeability test. The two stages are presented hereafter and in the subsequent sections.

Materials

Ordinary Portland Cement (O.P.C)

Locally produced O.P.C in accordance with the Egyptian standards was used throughout this investigation. Standard physical, mechanical, and chemical tests were carried out on cement samples according to B.S. 12/1978 [5] and Egyptian Standards 373/1990 [6]. The results of the tests conducted on the cement used are given in Tables (1) and (2).

Coarse Aggregates

Crushed stone was brought from a quarry in Attaka-Suez. The aggregates were divided into two sizes: 14 & 20mm and re-mixed with the appropriate proportions for use in concrete. The aggregates were delivered clean, free from impurities, and stiff. The chemical and physical testing were carried out on different coarse-aggregate types according to B.S. 882/1976 [7], B.S. 812/1975: parts 1, 2, and 3 [8], and Egyptian Standards 1109/1971 [9]. Results of tests are given in Tables (3), (4), and (5) and Fig. (2).

Fine Aggregates

Natural dessert sand was used. It was delivered clean and free from impurities. The physical and chemical tests were carried out on this sand according to B.S. 812/1975 parts 1, 2, and 3 [8] and Egyptian Standards 1109/1971 [9]. Results of tests are given in Tables (3), (5), and (6) and Fig. (3).

Water

Tap water was used in mixing and curing test specimens.

Concrete Mixes

Research work was carried out using concrete mixes of different cement contents (250, 350, and 500 kg/m^3), sand of zone 2, and slump between 80 and 100mm. Mix proportions for the laboratory specimens are shown in Table (7). Standard 150mm cubes were used to prepare concrete specimens. Fourty two cubes were cast from each mix.

Preparation Of Concrete Specimens

Dry materials were weighed, placed in a concrete mixer, and dry mixed for one minute to ensure uniformity of mix. Water was added gradually during the mixing operation. To obtain a homogenous mixture, the period of mixing was about 2 minutes. To control manufactured concrete, consistency of each mix was measured by slump test according to B.S. 1881/1983: part 2 [10].

The 150mm cubes were cast in three equal layers. Each layer was compacted manually using a standard tamping rod 16mm in diameter. Twenty five strokes were given to each layer. Concrete surface was levelled using a trowel. The specimens were demoulded 24±8 hours after casting and were then either air or water cured for 3, 7, or 14 days until the time of testing. Two cubes, from each mix and of the same curing regime, were tested at each age.

RESULTS AND DISSCUSION

The Air Permeameter

The impermeability index is plotted in Fig. (4) for concrete specimens with different W/C ratios, ages, and curing regimes. It can be seen that the impermeability index is greatly affected by W/C ratios. This was also shown by other researchers [11 and 12].

For the impermeability index, water cured specimens exhibited lower permeability (higer index) than the air cured ones. This is probably due to the improvement of the pore structure of the water cured specimens [4]. However, this effect seems to be more pronounced at low W/C ratios. This may be explained by the fact that the lean (mixes high W/C ratios) do not benefit from prolonged water curing as rich ones because the mixing water is more than enough for hydrating the available cement in lean concrete. With low W/C ratios, however, the hydration reactions continue in the presense of water. Therefore, the impermeability is improved dramatically with water curing.

The effect of age on impermeability index was realized as follows: for young concrete, the relationships are less sensitive to W/C ratio (flat curves) than at later ages. It is argued that this may be due to the lack of appreciable amounts of hydration products at early ages regardless of the W/C ratio. At later ages, however, low W/C ratio concrete becomes less permeable because of the disconnection in capillaries.

Capillary Absorption Test

In order to assess the efficiency of the developed Air Permeameter test, the Capillary Absorption test [13] was carried out and the results were compared. The later was conducted as outlined hereafter.

Standard concrete specimens were dried in oven at age of testing at 105° C until constant weight (i.e. difference in weight $\leq 0.2\%$) is aquired. Although heat causes some micro cracking for test specimens, this was found to be the easiest way to obtain consistent results. Cube sides were greased, weighed and then immersed in water container over steel rods (see Fig. 5). Every five minutes, samples were shaken, dried quickly with a cloth, and the weight was recorded. Gain of weight and time relationship were plotted in order to obtain the coefficient of absorption. The rate of weight gain at steady state (slope of the linear portion of the curve) is the absorption coefficient. Kelham [13] was the first to propose the Capillary Absorption test. The test is popular for its simplicity and ability to simulate water penetration into dry or semi-dry concrete.

The results of the absorption test are shown in Fig. (6) for all specimens of this investigation. It can be seen that the increase in W/C ratio increases the absorption coefficient. This effect is expected since the increase in W/C increases the total porosity and capillary connectivity of concrete [14].

Figure (6) shows that capillary absorption is slightly affected by the curing regime. This may be explained by the fact that specimens subjected to both types of curing regimes are oven dried prior to this test. Oven drying is known to cause microcracking and therefore the benefits of water curing are not observed. In addition, the period of curing is insufficient for drawing final conclusions about the effect of type of curing on the test results.

It should be noted that the age of testing (3, 7, or 14 days) has a profound effect on the gain of weight during Capillary Absorption test. The older the specimens, the less the water absorbed and hence the lower the coefficient of absorption. This can be explained by the fact that concrete absorbs more water if there are empty spaces available (as in the case of young concrete where hydration reaction products are limited in volume). However, it should be noted that the Capillary Absorption test is mainly a laboratory technique and is clearly inadequate for in-situ investigation of concrete.

Relationship between the impermeability index and coefficient of absorption

The relationship between the impermeability index and coefficient of absorption is outlined by the 'best fit' curve shown in Fig. (7). It can be seen that there is some scatter in the results as both tests are different in many respects (e.g. zone of concrete tested, type of fluid permeated, ..., etc.).

However, and based on the discussion in the previous sections, it is concluded that the developed Air Permeameter test is superior to the Capillary Absorption test for in-situ assessement of the quality of concrete. This superiority is further assured by demonstrating the appartus's sensitivity to the parameters studied in this work (e.g. curing) as shown in Figs. (4) and (6).

IN-SITU APPLICATION OF THE AIR PERMEAMETER TEST

Series of tests were carried out to investigate the applicability of the proposed test in-situ. The tests were conducted at a new construction site in Cairo. Preparation for in-situ experimentation of the apparatus is shown in Fig. (8). Figure (9) demonstrates how the test is conducted.

Measurements were taken at three points in each of the following structural members:

a- Interior column.
b- Exterior column.
c- Interior beam.
d- Exterior beam.

The results are shown in the schematic diagrams of the structural members (Figs. (10) and (11)). It can be seen that the results are not identical throughout each structural member. However, the values are close. This behavior is expected and can be explained by the fact that different points in a structural member may not be subjected to the same degree of vibration during casting. Therefore some variation in the concrete quality can be found. However, this variation should be small in well compacted concrete made from the same mix. This indeed was the case in the members studied.

In general, no problems were encountered in conducting the test in-situ. More investigations are planned with the purpose of building up a data-base for in-situ results. This would help in giving a fair idea about the quality of the tested concrete.

CONCLUSIONS

1: An air permeability test apparatus was developed for this investigation. The components of the apparatus are cheap and simple to assemble.

2. The developed test was used in studying a range of concrete mixes with varying W/C and curing regimes at different ages. The test results were comparable to the capillary absorption measurements and were sensitive to the concrete quality.

3. The developed test technique was pilotted in-situ. No problems were encountered in the application. This demonstrates its portability. The results are believed to be representative of the concrete properties in the structural members.

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Table 1. Physical and mechanical properties for ordinary Portland cement samples.

Property	Test result	E.S.S 373 Limitation
Blain Specific Surface Area (cm^2/gm)	2580	< 2500
Standard Consistency Water %	24.2 %	-----
	Hr Min	
Initial Setting Time	2 35	< 45 Min.
Final Setting Time	4 50	> 10 Hr.
Soundness mm	1.5	> 10
Compresive 3 days	210.0	180 Kg/cm^2
strength 7 days Kg/cm^2	335.0	270 Kg/cm^2

Table 2. Chemical analyses for ordinary Portland cement samples.

Test	Results
Insoluble residue	0.94 %
Sulphates as So_3	2.50 %
Loss on Ignition (LoI)	2.80 %
Ferric Oxide (FeO)	3.41 %
Aluminum Oxide (AlO)	5.51 %
Calcium Oxide (CaO)	63.10 %
Magnesium Oxide (MgO)	4.67 %
Silicon Dioxide	19.52 %

Table 3. Physical properties of aggregates.

Property	Aggregate type	
	Sand	Stone
Specific gravity	2.58	2.67
Crushing value %	--	25.7
Absorption value % (by weight)	1.0	1.70

Table 4.a. Sieve analyses of crushed stone (size 1).

Sieve opening (mm)	14	10	6.3	5.0
% Passing by weight	100	95.2	31.4	18.05

Table 4.b. Sieve analyses of crushed stone (size 2).

Sieve opening (mm)	20	14	10	5.0
% Passing by weight	100	63.13	0.87	0.0

Table 5. Chemical properties of aggregates.

Chemical analysis % by weight	Aggregates			
	Sand	Limit	Stone	Limit
Chloride as cl^-	0.05	0.06	0.02	0.3
Sulphate as So_3^{--}	0.037	0.4-0.5	0.018	0.4-0.5
Total dissolved salts	0.15	0.00	0.078	0.00
PH	7.80	6.0-8.0	7.72	6.0-8.0

Table 6. Sieve analysis of fine aggregates (sand).

Sieve opening mm	5.0	2.36	1.18	0.6	0.425	0.15	0.075
% passing by weight	100	95.5	86.75	56.5	35.5	4.0	0.75

Table 7. Mix proportions of stone concrete.

Mix	Mix Quantites for lm^3 concrete -by weight- Kg/cm^3					Mix proportions -by weight-
	Cement	Water	Sand	Stone size1	Stone size2	Cement:sand:stone
A	500	202.0	609.3	578.6	578.6	1.0 :1.22:2.31
B	350	204.0	741.3	604.7	604.7	1.0 :2.12:3.46
C	250	206.0	849.7	586.7	586.7	1.0 :3.40:4.69

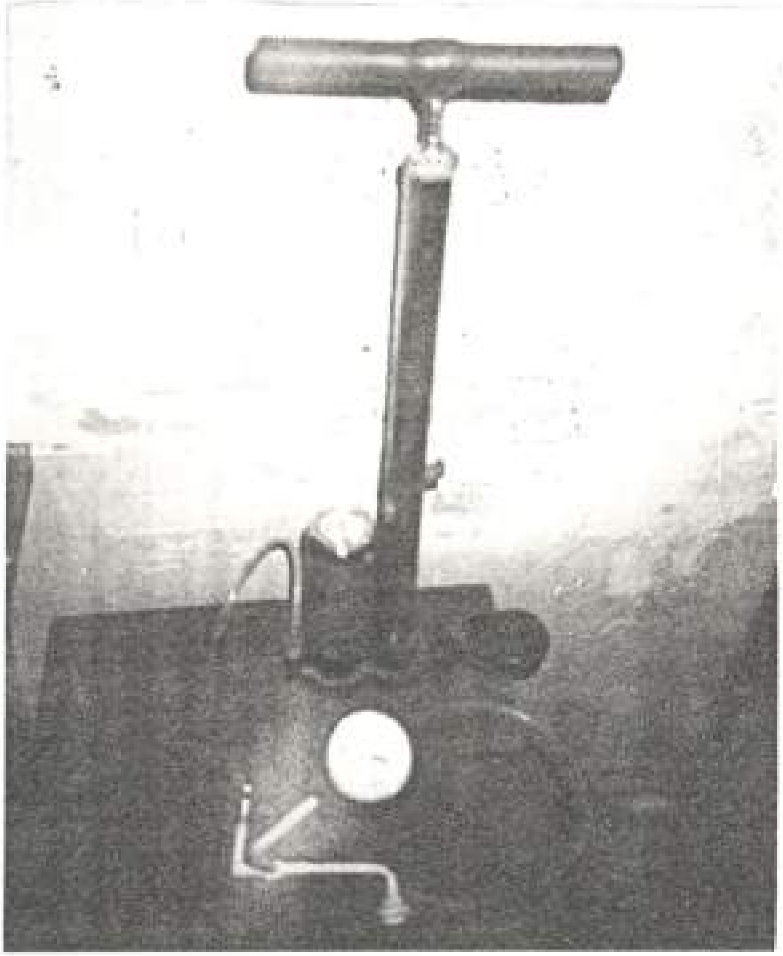


Fig. 1. The Air Permeameter.

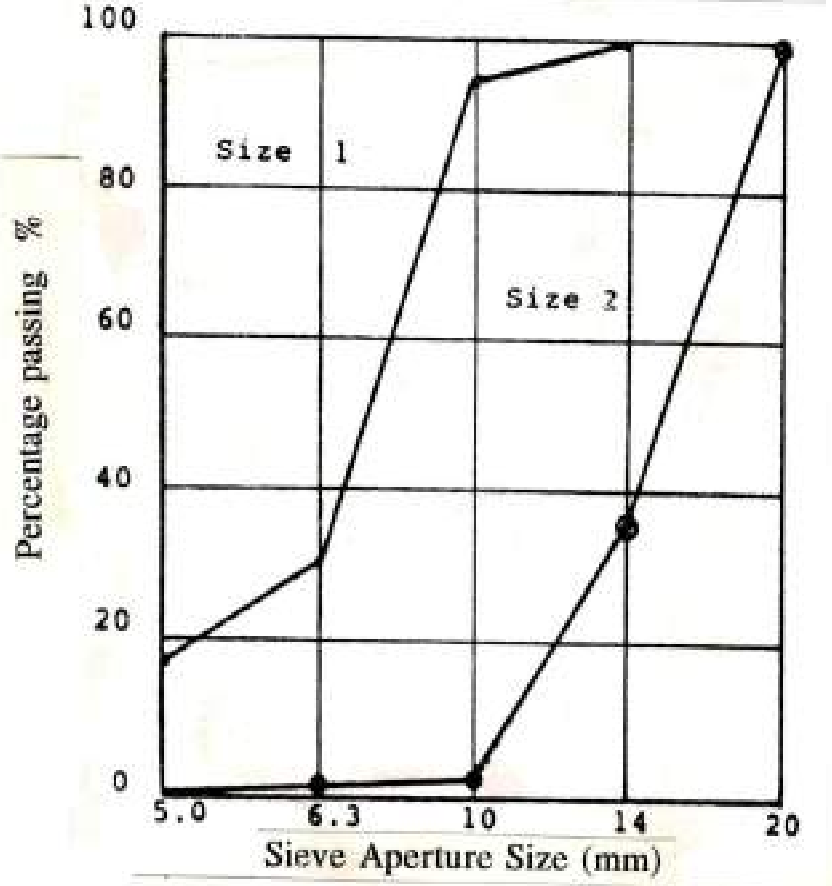


Fig. 2 Sieve analysis of crushed stone.

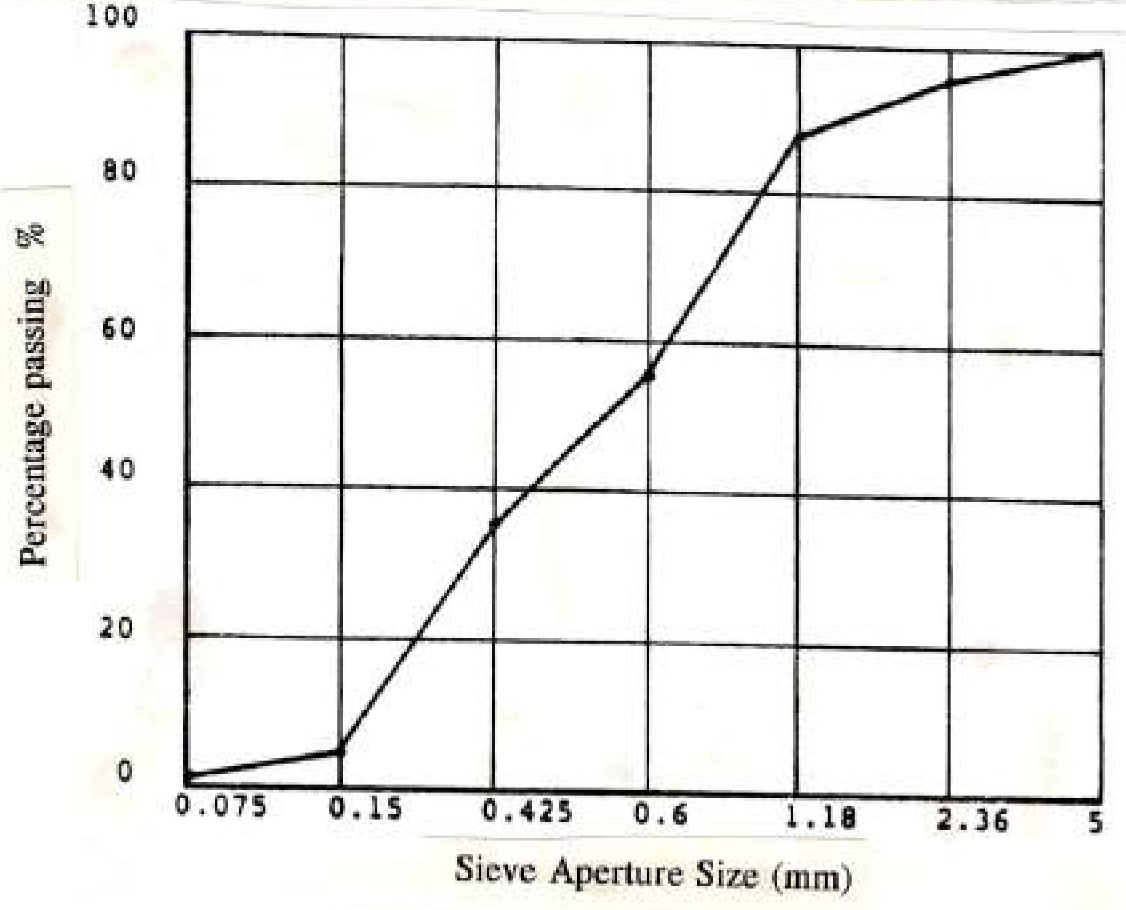
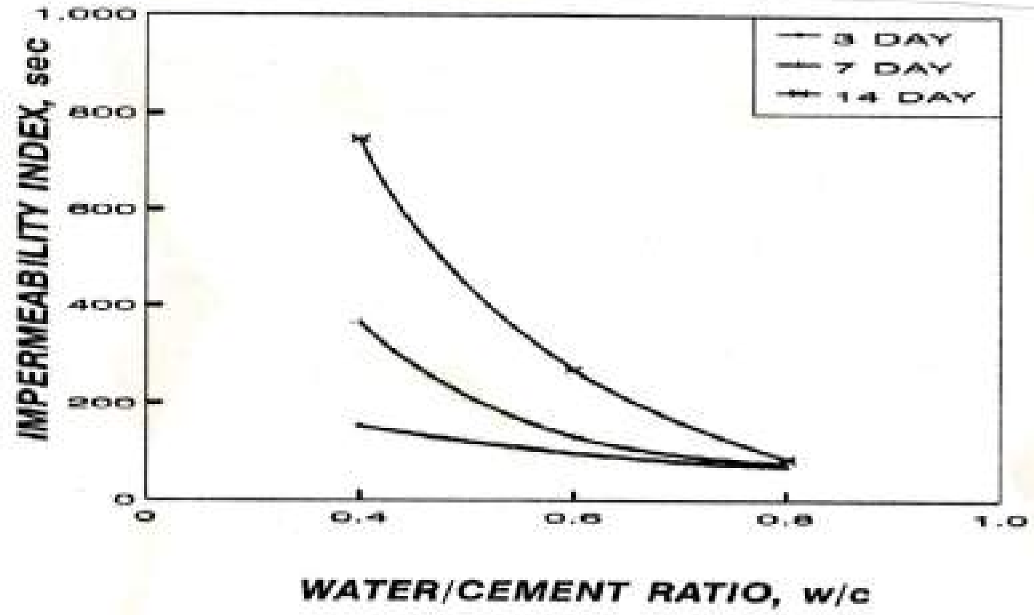
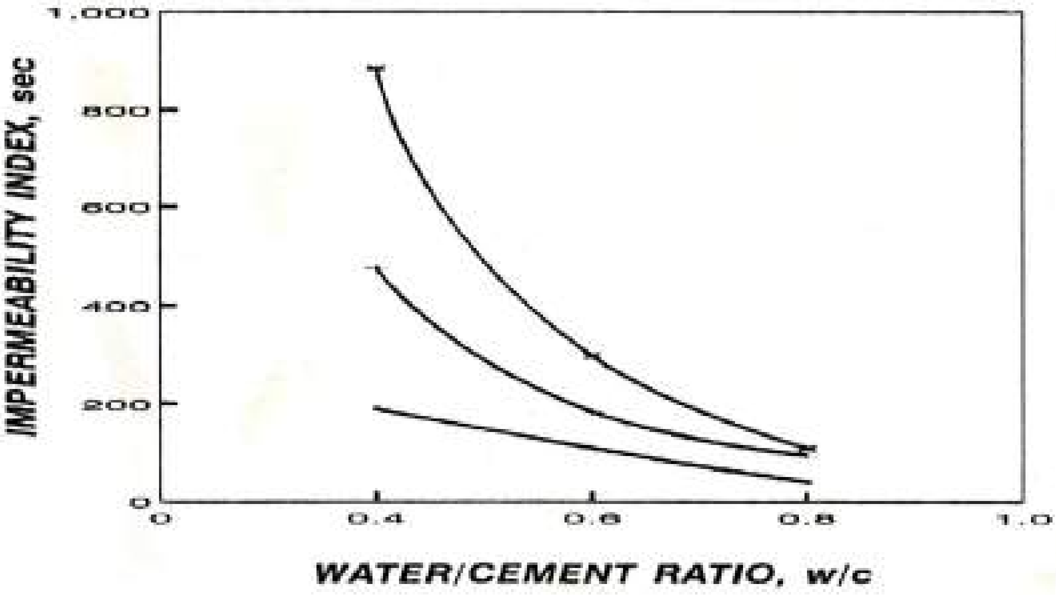


Fig. 3 Sieve analysis of used sand.



(a) Air-curing



(b) Water-curing

Fig. 4 Impermeability index and W/C ratio relationship for different ages of testing.

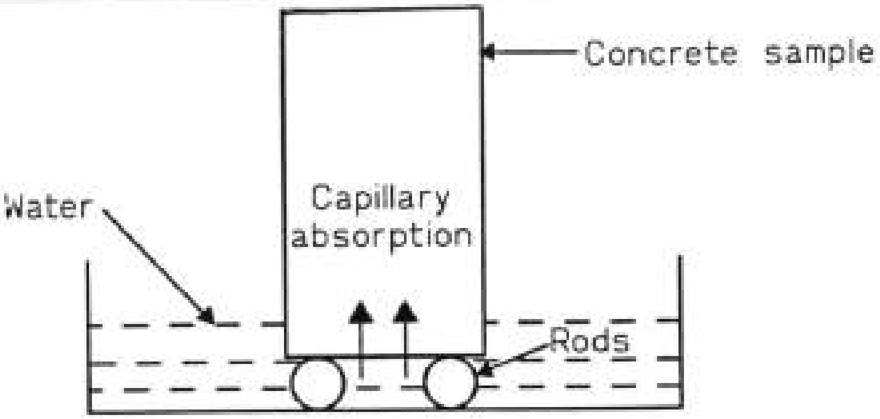
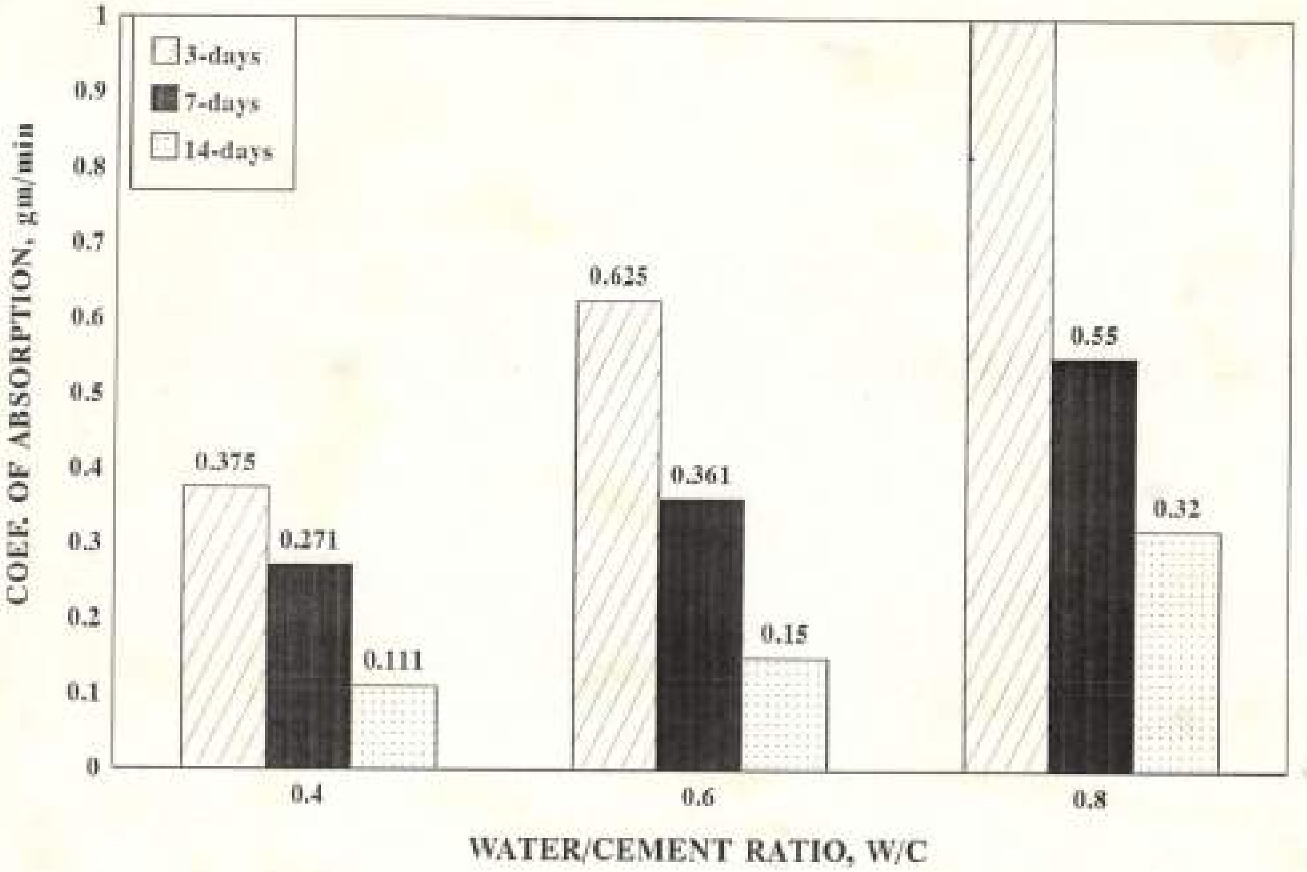
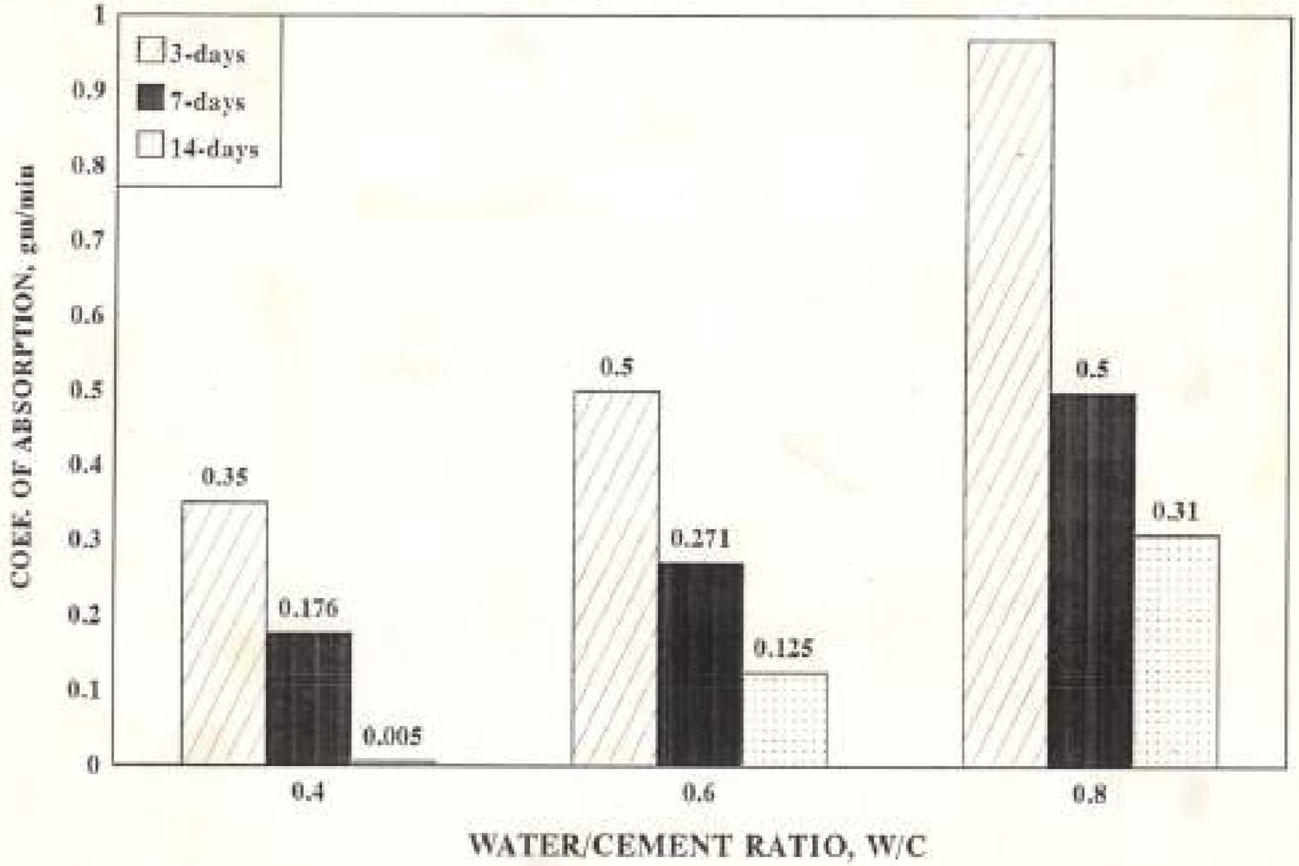


Fig. 5 The Capillary Absorption Test.



(a) Air-curing



(b) Water-curing

Fig. 6 Effect of curing and test age on absorption properties for different W/C ratios.

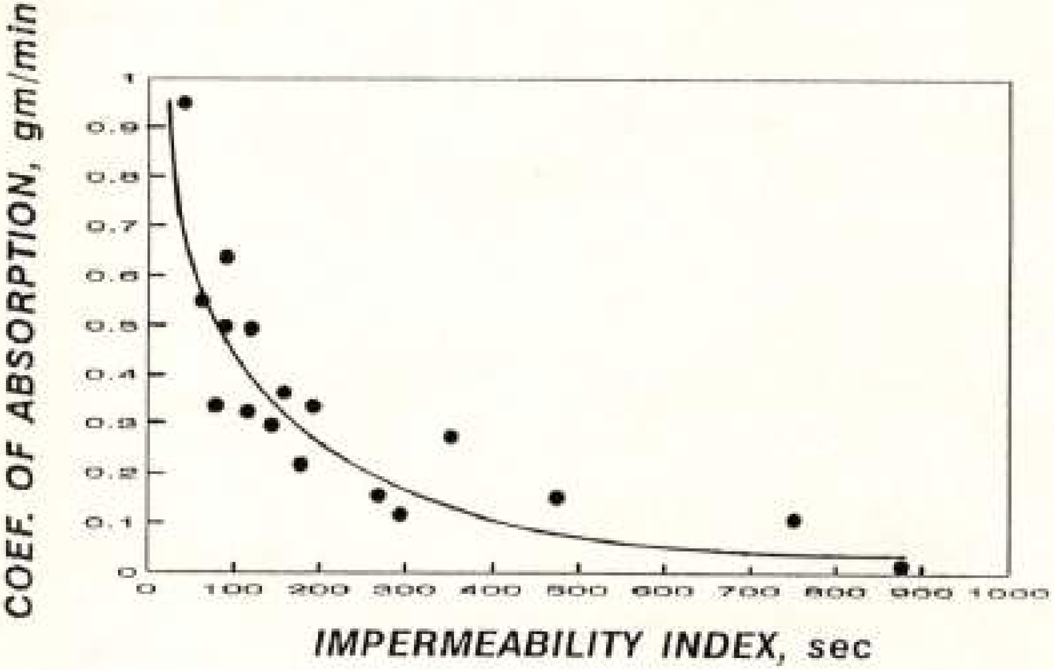


Fig. 7 Coefficient of absorption and impermeability index relationship.

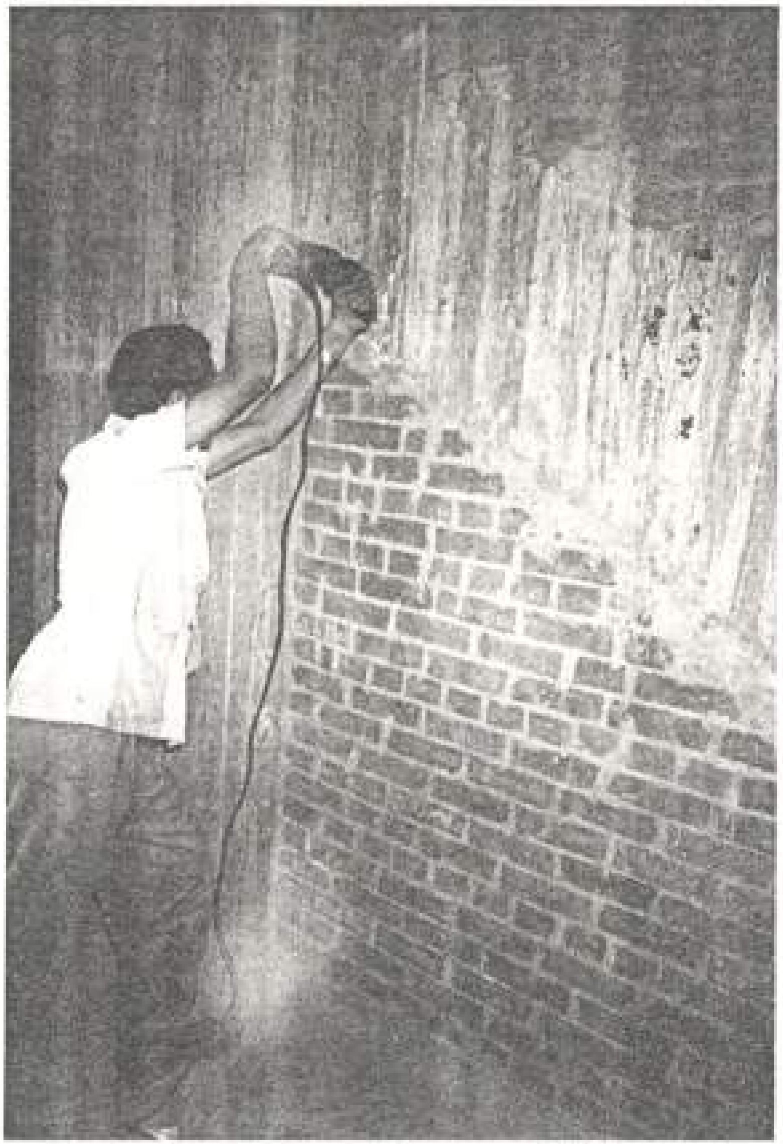


Fig. 8. In-situ setting of the air permeability test
(Air Permeameter).

Fig. 9. In-situ application of the air permeability test (Air Permeameter).

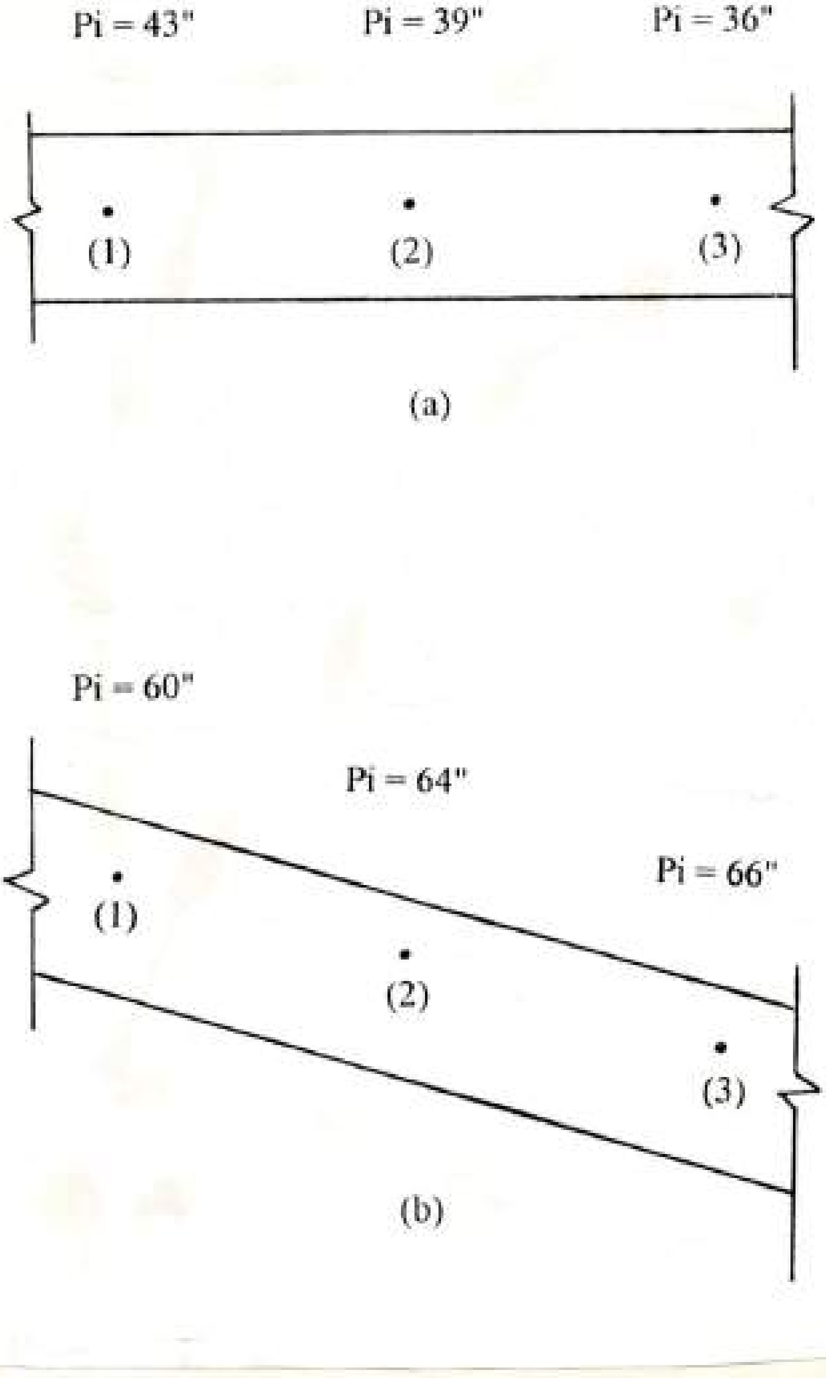
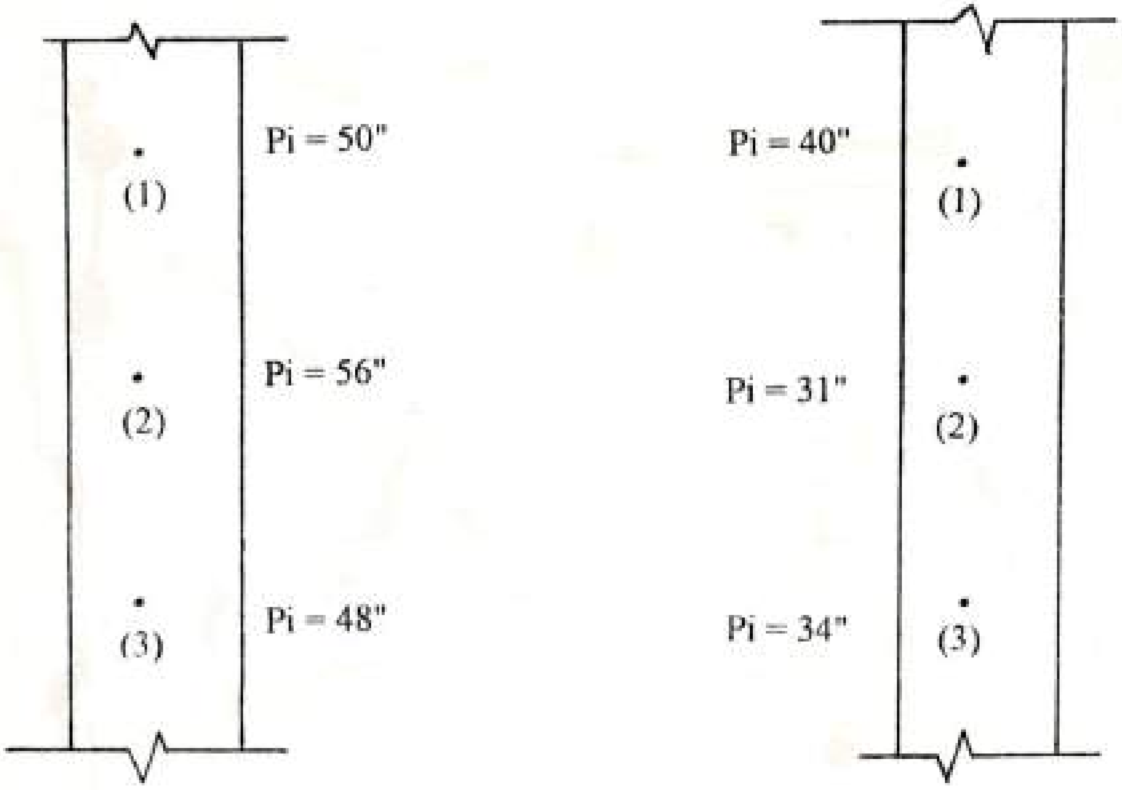


Fig. 10 Schematic view of the test locations and results in the test beams.



Interior Column

Exterior Column

Fig. 11 Schematic view of the test locations and results in the test columns.