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A LABORATORY INVESTIGATION ON THE EFFECTIVE PARAMETERS OVER THE PENETRABILITY OF ROLLER COMPACTED CONCRETE

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ABSTRACT
Roller Compacted Concrete construction technique has been recently remarkably considered in Iranian academic centers and dam engineering industry. However, research studies can hardly be found in which physico - mechanical properties of RCC have been studied as in a real ongoing project. In this study, permeability of the mass of RCC mixture used in Zirdan RCC dam located in south of Iran, the second large RCC dam in Iran has been investigated. Influences of cementitious material content, water - cement ratio, pozzolan replacement ratio in cementitious material, delay in working time and age of concrete specimens on permeability coefficient have been studied. Moreover, effects of different types of pozzolan on permeability have been examined.results showed that RCC has an equal or even lower permeability coefficient in comparison to an equivalent ordinary concrete. Effect of water content on permeability was considerable and in comparison to cementitious material content, showed a higher degree of importance. The rate of developing permeability coefficient (decreasing) was found faster than the rate of mechanical strength development (increasing). Delay in working time decreased the permeability of RCC. However, decreasing the water content below its optimum limit would result in an excessively high permeability coefficient.
Finally, it was observed that silica fume had a significant effect on permeability coefficient.

Keywords: RCC, permeability coefficient, pozzolan, silica fume, working time

1. INTRODUCTION

Permeability of RCC mass is one of the most important parameters in RCC dams, and also in Roller Compacted Concrete Pavements (RCCP). This is due to direct relationship between this parameter and problems such as water leakage through dam body, pore water pressure, stability in freezing and thawing cycles, and durability requirements. Water leakage may have deteriorating effect on hardened RCC strength by washing away cementitious materials.

Also, freezing and thawing cycles would, have undesirable effects on highly permeable concrete. On the other hand, design of mixtures with sufficient impermeability may lead to omission of several extensive works such as upstream

impermeable faces, resulting in positive effects on. technical and economical aspects ofproject.
Two different aspects of RCC, concrete and soil aspects, have leaded in two different theories about RCC permeability. Considering concrete approach, permeability is related to the content of cementitious material in RCC mixture [1,2]. According to soil approach, on the other hand, increasing the amount of cementitious material will not result in significant change in permeability coefficient in the case designing a suitable RCC mixture proportioning. In fact, it is possible to achieve RCC permeability coefficient as low as a conventional concrete mixture's and using low content of cementitious material [3].
Although a few studies have been formerly conducted on RCC permeability [4,5], our understanding of this vital property of RCC IEemains far from adequate. In addition, pure theoretical researches cannot provide useful, adequate and practical ways to address RCC issues which are currently just the fruit of innovations of contractors and designing engineers.
Having these facts in mind, we were encouraged to investigate the influence of several factors on RCC mixture permeability of Zirdan RCC dam, the second large RCC dam in Iran considering technical, economical and constructional aspects. The dam's study phase test fills of this dam is going on and the placement works is about to start.

2. EXPERIMENTAL WORKS

2.1. Materials

As previously mentioned, materials used in this study were those ones currently used in Zirdan RCC dam. The details are as follows:
Zirdan riverbed materials have been used as aggregates. As it is currently employed in site, two classes of aggregates have been considered: 1- sand (0-4.75 mm) 2- gravel (4.75-37.5 mm), these two classes are mixed in a 40:60 proportion, respectively.
Cement Type II has been used in study. Results of its chemical analysis and physical properties are presented in Table [1]. The main applied pozzolan is Khash pozzolan. A type of silica fume, slag and another natural pozzolan type (Trass) have been employed for comparison. Pozzolan chemical analyses are presented in Table [2].
In order to respond to research questions, several mixture proportions have been applied.
Results obtained from all tested mixtures with their physical and mechanical properties are presented in Table [3].

Table 1: Cement chemical composition

Sio2	Al2O3	Fe2O3	CaO	MgO	SO3	K2O	Na2O	Cl	LOI	C3A	C4AF	C25
21.31	5.24	3.24	63.04	2.49	2.06	0.31	0.52	0.017	0.58	7.44	11.7	0.67

Table 2: Pozzolan composition.

Pozzolan	Na2O	K2O	SO3	MgO	Ca0	Fe2O3	Al2O3	SiO2
Khash	2.72	2.66	0.1	1.7	7.8	4.96	14.54	61.14
Silica Fume	0	0	0	1	2.1	1.5	1.4	90
Trass	0	0	0	1	2.4	0.8	12.3	67
Slag	0	0	1.6	9.06	38	0.71	10.5	35.7

2.2. Test Procedure

Cylindrical specimens have been made according to ASTM C II 76-98 [6], using a modified Ve Be table; the only difference to the mentioned code is that the specimens are made in two 10 cm high layers. Therefore, their height is 20 cm. It means 10 cm shorter than the standard specimens. The specimens have been stored in 20 ± 2°C water.

The measurement of the permeability coefficient was performed by the method shown in Figure [1].During 48 hours before the permeability test the cylindrical specimens were conditioned at 50 % HR and 20°C. Then, the 6 atm water pressure was applied for 24 hours on a circular concrete surface area of 7.5 cm in diameter. Surrounding this circular surface was wate highte by bituminous material. After 24 hours of sustained pressure, the specimen was split and the depth of penetration {d) was obtained. In this case, the permeability coefficient (K_v) was derived from the (Eq. [1]) developed by Valenta [7].

$$K_v = \frac{d^2 V}{2ht} \qquad (1)$$

V is the volume voids filled by water in the penetrated zone, (determined by measuring gain), h is the head of water and t is the time to penetrate to depth (d).

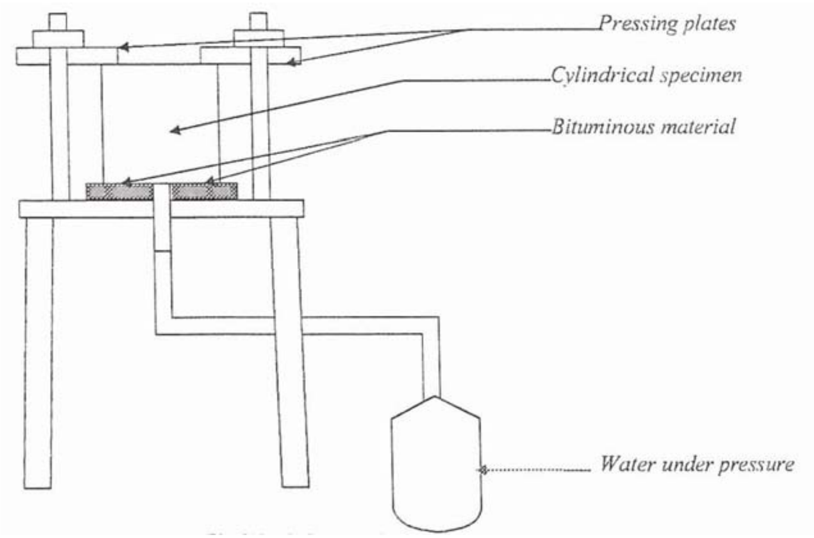


Figure 1. Scheme of permeability test

3. RESULTS AND DISCUSSIONS

The permeability coefficients obtained are presented in Table [3]. Table [3] also includes compressive strength of specimens. Effects of different parameters on permeability are described below [8].

Table 3: Mixture properties and test results

ID	C+P (kg/m^3)	P (kg/m^3)	W (kg/m^3)	W/(C+P)	Pozzolan Type	Consistency (sec)	Age (day)	K (cm/s)	fc (MPa)
A1	200	60	110	0.55	Khash	35	28	2.65E-10	14.3
A2	180	54	110	0.61	Khash	35	28	6.17E-10	13.2
A3	160	48	110	0.69	Khash	35	28	1.21E-09	13.8
A4	140	42	110	0.79	Khash	35	28	1.55E-09	9.4
R1	110	0	110	1	------	40	28	6.14E-09	7.9
R2	110	22	110	1	Khash	38	28	4.38E-09	8.5
R3	110	33	110	1	Khash	36	28	2.89E-10	9.4
R4	110	44	110	1	Khash	34	28	5.04E-09	8.3
R5	110	55	110	1	Khash	30	28	1.95E-08	7.5
R6	110	66	110	1	Khash	26	28	2.37E-08	6.8
W1	130	52	39	0.3	Khash	120	28	1.00E-03	6.5
W2	130	52	65	0.5	Khash	65	28	4.24E-10	12.0
W3	130	52	91	0.7	Khash	30	28	3.13E-09	11.2
W4	130	52	117	0.9	Khash	12	28	7.13E-09	9.8
W5	130	52	143	1.10	Khash	6	28	1.93E-08	6.4
G1	200	80	115	0.58	Khash	30	3	1.78E-08	4.8
G2	200	80	115	0.58	Khash	30	7	3.97E-09	6.7
G3	200	80	115	0.58	Khash	30	14	8.13E-10	9.8
G4	200	80	115	0.58	Khash	30	21	9.25E-10	11.8
G5	200	80	115	0.58	Khash	30	28	3.56E-10	12.1
K1	200	0	115	0.58	------	40	28	7.33E-11	15.0
K2	200	100	115	0.58	Khash	33	28	9.63E-10	12.9
K3	200	100	115	0.58	Trass	32	28	2.38E-08	10.3
K4	200	100	115	0.58	Slag	27	28	2.70E-10	13.4
K5	200	20	115	0.58	SF	29	28	1.16E-11	20.9

C: Cement
P: Pozzolan
W: Water
K: Permeability coefficient
fc: Compressive strength

3.1. Influence of Cementitious Material Content

As can be seen in Figure [2], an increase in cementitious material from 140 to 200 kg/m3 has not shown a significant decrease in permeability coefficient though having a remarkable positive effect on mechanical strength. According to this

Figure, mixtures having acceptable permeability coefficient would be obtained using low cementitious material content.

Although increase of cementitious material would result in a better mechanical strength, no such significant effect is observed for permeability coefficient.

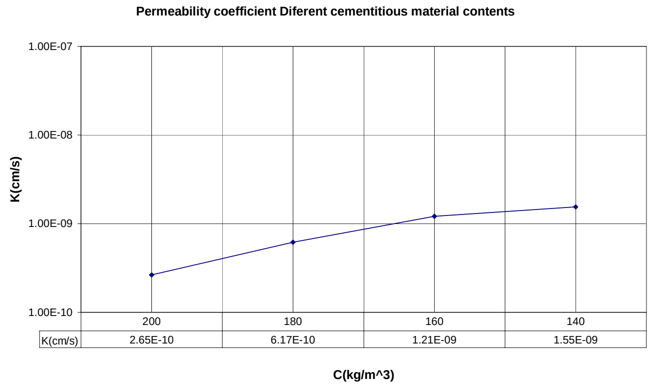


Figure 2. Effect of cementitious material content.

3.2. Influence of Water to Cement Ratio

According to Figure [3], optimum water to cement ratio is estimated 0.55. The diversity of results shows an implication of importance of water content in RCC mixture, instead of water to cement ratio as in ordinary concrete. Another conclusion obtained from Figure 5 is that while water content is increased from its optimum level, insignificant increase in permeability coefficient would be obtained, whereas decreasing water content from the optimum level, even very low content, leads to decrease the compaction factor, and shows an excessive increase in permeability coefficient.

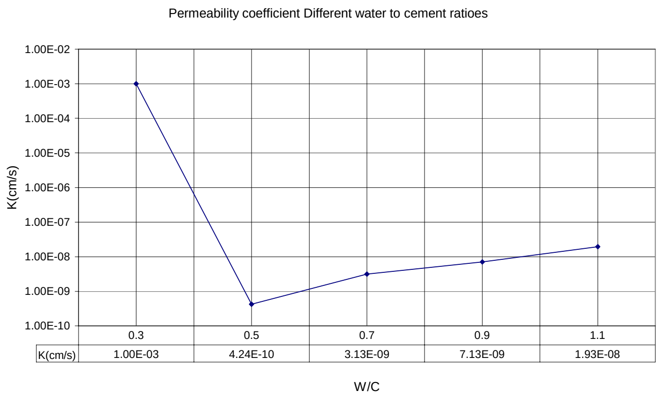


Figure 3. Effect of water to cement ratio.

3.3. Influence of Pozzolan Content

According to Figure [4], the lowest permeability coefficient would be obtained using optimum replacement ratio of pozzolan (in this study, 30% for the main applied pozzolan). Using higher replacement ratio (e.g. 50%), especially in short ages (up to 28 days) would increase permeability coefficient.

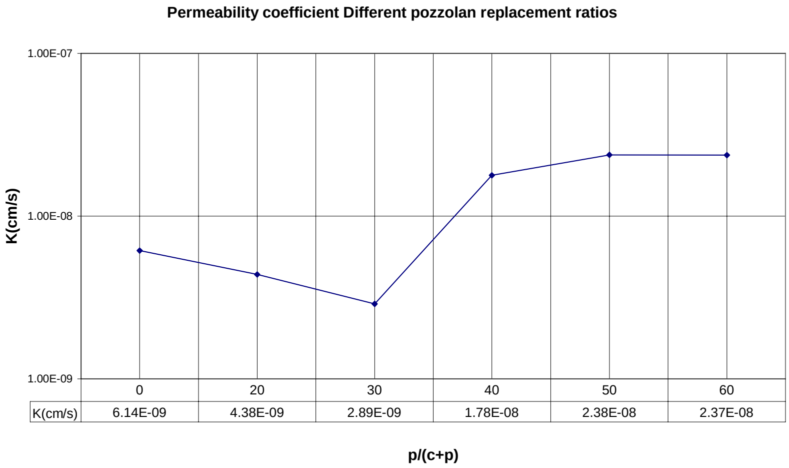


Figure 4. Effect of pozzolan content

3.4. Influences of Age in Working Time

As can be seen in Figure [5], rate of permeability coefficient development shows a different 1· trend to that of for mechanical strength development. Mechanical strength of cemented mixtures as well as RCC increase significantly during the first 28 days, while RCC permeability coefficient do not shows remarkable decrease after 14 days in this study. This is in case that 40% of cementitious material is pozzolan.

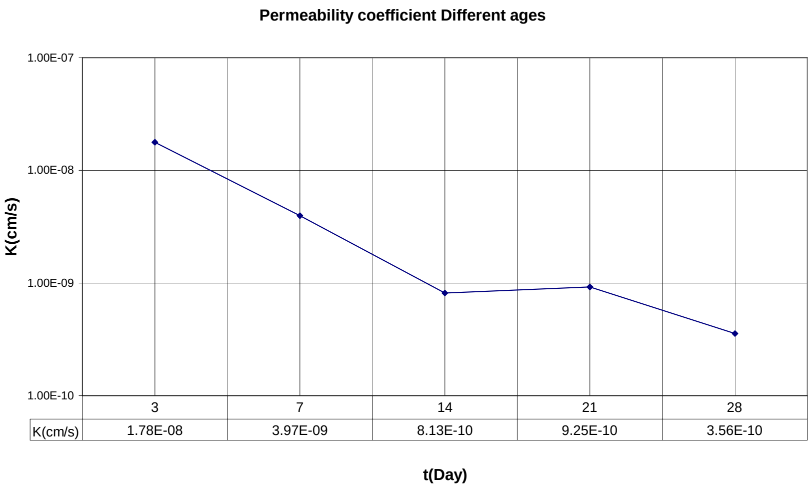
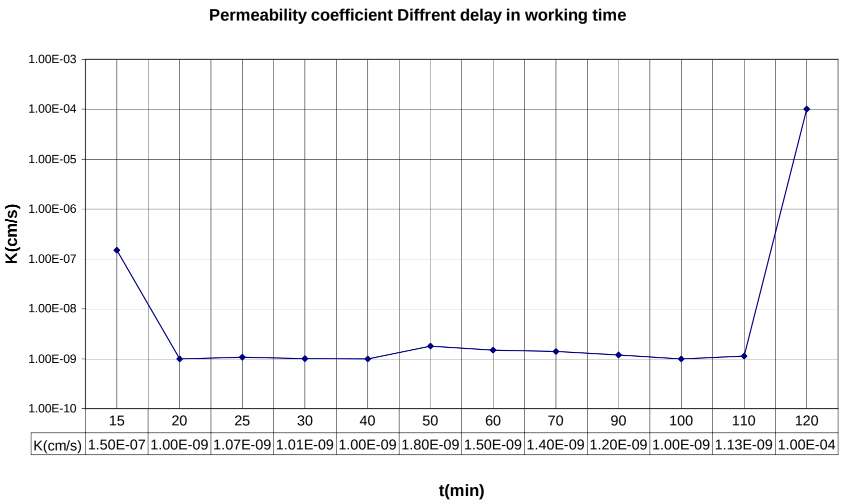


Figure 5. Effect of age

3.5. Influences of Delay in Working Time

Effect of delay in working time (compaction time) is shown in Figure [6]. Dasmeh et al. [9,10] reported that employing pozzolan in cementitious material would extend allowable compaction time. In that study they showed that specimens containing pozzolan in their cementitious material and made after 120 min. delay in compaction time had shown an improve in mechanical strengths. The results obtained from present study on compaction time indicate that it is possible to achieve a lower permeability coefficient for specimens compacted after a delay of up to 110 min. However, the results obtained from specimens compacted with a delay longer than 110 min. illustrate a notable increase of permeability coefficient. It may be due to evaporation of water of mixture. Therefore, decreasing the water content below its optimum limit which would result in an excessively high permeability coefficient.



t(min)	15	20	25	30	40	50	60	70	90	100	110	120
K(cm/s)	1.50E-07	1.00E-09	1.07E-09	1.01E-09	1.00E-09	1.80E-09	1.50E-09	1.40E-09	1.20E-09	1.00E-09	1.13E-09	1.00E-04

Figure 6. Effect of delay on working time

3.6. Influences of Type Ofpozzolan

The effect of use of silica fume in reduction of the permeability coefficient of Conventional Vibrated Concrete (CVC) has been shown by several authors [11,12]. For Roller Compacted Concrete (RCC), excellent effect of employing silica fume in cementitious material is presented in Figure [7]. In comparison to mixtures containing other types of pozzolan in their cementitious material, and also to mixture without any additive in its cementitious material, a remarkably lower permeability coefficient has been obtained when applying silica fume. The result is due to the fact that using silica fume in the mixtures would improve the "Transition Zone", change capillary pores to gel poreS3 and seal their inter connections. It can also be seen that replacement of slag up to 50% of cement could lead to considerably good results. The main pozzolan applied in this study (obtained from Khash area) has also shown acceptable results regarding permeability coefficient as well as mechanical strength.

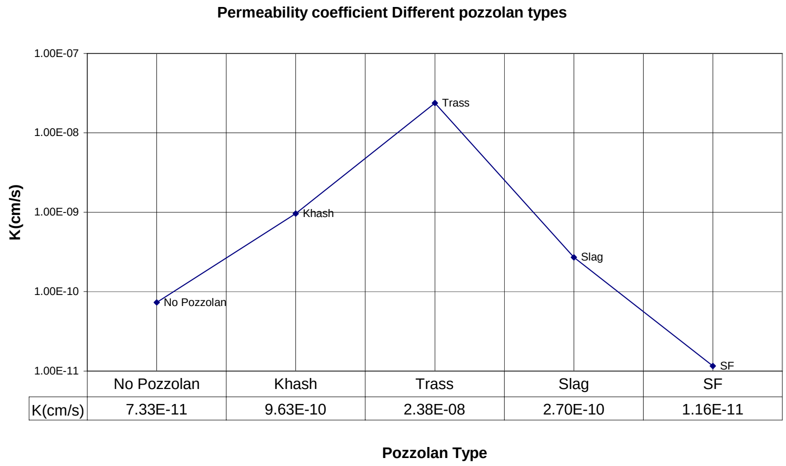


Figure 7. Effect of type of pozzolan

3.7. An Observation: Tortuousity Effect

Some of specimens in this study showed greater values for horizontal permeability coefficient than vertical permeability coefficient. This is an implication of fast evacuation of streamlines through side-walls. The difference between permeability coefficient of two horizontal and vertical directions can be justified as follow: Aggregates including high percentage of flat and elongated particles are allowed to be used in RCC mixtures (coarse aggregate used in this study contains 30% of flat or elongated particles). RCC compaction methods on the other hand, would arrange these particles in horizontal direction. This arrangement of particles is the reason for a phenomenon called "Tortuousity" which increases the length of streamlines in vertical direction. Consequently this increase would result in a lower vertical permeability coefficient and higher value in horizontal direction. This problem should be paid attention when evaluating RCC dam required permeability coefficient. The phenomenon "Tortuousity" is illustrated in Figure [8].

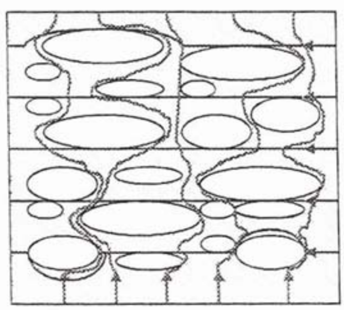


Figure 8. Tortuosity effect

4. CONCLUSION REMARKS

Brief summery of the findings is described below:

1) Influence of water content of RCC mixture on permeability was found vital and

in comparison to cementitious material content has a greater degree of importance.
2) Employing pozzolan up to its optimum replacement ratio in cementitious material decreased the permeability coefficient.
3) Inpite of mechanical strengths, the rate of permeability coefficient improvement was considerable up to first 7 to 14 days.
4) Delay in compaction time would improve permeability coefficient of specimens containing pozzolan in their cementitious material unless it results in a decrease of water content below its optimum limit.
5) Effect of using silica fume in RCC mixture was excellent. Also employing slag in cementitious material had considerable positive effects on the reduction of permeability coefficient. Considering the low price of slag, it is recommended to replace it in great percentages in cementitious material.
6) The RCC permeability coefficient could be much less than 3x10-9 cm/s, a typical value for conventional concrete permeability when using low cement content. In case of using flat and elongated aggregates, different values would be obtained for horizontal and vertical permeability coefficient.

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