EARLY PREDICTION OF RCC DAM BODY PERMEABILITY DURING CONSTRUCTION - CASE STUDY: DYRAABA DAM, SRI LANKA

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ABSTRACT

Roller compacted concrete (RCC) has become a popular material in recent decades for dam and pavement design. Because of higher speed of construction and lower cost, it is an affordable method of construction. In dam design, permeability is one of the parameters with an utmost importance. Quality control through the measuring of fresh concrete characteristics and related tests have considered as the most essential activity in dam construction sites. On time assessment of suspicious fluctuation in test results could be lead to remedial actions. In this paper density of fresh concrete, compressive strength and Vebe-Time of RCC have been used to early prediction of permeability RCC cores of Dyraaba dam body that is located in Sri Lanka. Regression mathematical method has been used to develop linear and logarithmic equations in order to predict permeability of RCC used in dam body. Results show that among the different parameters of concrete, fresh concrete density and early compressive strength (7days) are the most effective parameters on the permeability of RCC. Using developed equations for early prediction of permeability in dam body will lead to improvement of method statement and excessive repairing costs could be avoided.

Key words *: RCC Dam, Permeability, Vebe time, Compressive strength, Density, Regression*

1. INTRODUCTION

By emersion of concrete arch dam, a steady decline in the construction of concrete gravity dams has been started. Because in narrow valley sites concrete arch dams were more efficient and in wide valley sites embankment dams were more affordable. But because lower safety of embankment dams, engineers began searching for a new type of dam that combined the efficiencies of embankment dam construction with reduced cross-section and potential public safety advantages of concrete dams.

Roller compacted concrete (RCC), same as convectional concrete (CVC), is a mixture of coarse and fine aggregates, water, cementitious materials and required admixtures, with no-slump consistency in its unhardened situation. The name of RCC has been achieved because of the construction method where it is placed with the help of paving equipment and will be compacted or consolidated with rollers. Because of similarities in properties of RCC and CVC, RCC is often use in concrete gravity dams and pavements instead of CVC.

Roller-compacted concrete (RCC) is an affordable method for the construction of dams and pavements because of lower cost, higher speed, less cement consumption and smaller environmental impact due to lower amount of cement in RCC mix designs. Achieving adequate compaction is essential in the development of the desired properties in the hardened material. The compaction depends on many variables, including the materials used, mixture proportions, mixing and transporting methods, discharge and spreading practices, compaction equipment and procedures, and lift thickness. The best performance characteristics are obtained when the concrete is reasonably free of segregation, well-bonded at construction joints, and compacted at, or close to, maximum density[1].

An appropriate RCC mix should have suitable workability, consistency, impermeability, density, strength, and durability without using excessive cementitious materials. Several component will have effect on the permeability of RCC, however, in this research, the effect of three main property of roller-compacted concrete (consistency, compaction and strength) on the permeability of it, have been studied.

Several research have been conducted on different properties of Roller-Compacted Concrete (RCC) and Roller-Compacted Concrete Paving (RCCP).

Taha Mehmannavaz et al. (2012) studied the permeability of the mass of RCC mixture used in one of the largest RCC dam located in south of Iran. And 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 investigated.[2]

Seung-Kee Lee et al. (2017) evaluated the effects of reinforcement fibers on the mechanical characteristics, chloride ion penetration properties and abrasion resistance of roller-compacted latex-modified fiber-reinforced rapid-hardening-cement concrete.[3]

N.Banthiha et al. (2005) researched on permeability of concrete under stress. Its Special emphasis was placed on understanding the influence of stress application on the permeability on concrete at early ages (1–3 days).[4]

Chamroeun Chhorn et al. (2018) developed an equation to evaluate the relationship of compressive and tensile strengths of RCC and compare it with CVC. The results show that the flexural strength of the RCC is within the predicted values obtained from the conventional concrete equations for a given compressive strength. In contrast, the splitting tensile strength of the RCC is relatively lower than that of the conventional concrete for the given compressive strength.[5]

C.Chhorn et al. (2017) investigated the variation of quality of RCC based on its consistency and suggested the possibility of an ideal range of consistency that may provide adequate quality of roller-compacted concrete paving (RCCP).[6]

Mohammad Hashemi et al. (2019) studied the effect of using low fines content on the fresh and hardened properties of RCCP such as Vebe time, compressive strength, splitting tensile and flexural tensile strengths.[7]

A.C.Bettencourt Riberio et al. (2001) analyzed the influence of different parameters on the direct tensile strength of the joints, namely the relative humidity in the concrete surface, the setting and hardening state of the concrete, and the cold joint treatment.[8]

In the other study Zain et al. (2008) has used non-linear regression equation for the prediction of concrete compressive strength at different ages. But they have used different concrete mix designs for developing their equations. They showed non-linear regression is a reliable method to developing concrete equations.[9]

Khashman and Akpinar (2017) used artificial neural network (ANN) model to predict and classify the compressive strength of different concrete mixes into low, moderate or high strength and suggest to use it instead of traditional destructive compressive strength tests.[10]

Hasan and Kabir (2011) developed a simple mathematical model based on concrete's nature of strength gain to predict the compressive strength of concrete at 28th day from early age results. The model is a simple equation (a rational polynomial) that consists of two constants and one variable which is the age of concrete in days.[11]

Hossein Akbarzadeh Kasani (2016) proposed new linear and power relations for estimating 28 and 42 days strength values by analyzing on 382 datasets of ordinary Portland cement concrete.[12]

In large scale construction plants, especially in dam construction, using a particular mix design for a large amount of concrete is very common. This paper used mathematical methods in order to predict permeability of a particular mix design for RCC that is used in dam body of Dyraaba dam in Uva province, Sri Lanka. Consistency, compaction and compressive strength of RCC are three variables that have been considered to evaluate the quality of hardened concrete. Consistency is the key parameter for defining the constructability of RCC. The density is a factor with utmost importance in compaction of this kind of concrete, therefore density of compacted RCC is another variable that influence on permeability. And the last selected variable is compressive strength RCC that will be determined and is a suitable property in order to control the quality of RCC.

Because of its stiffness, typical slump test cannot be applied on RCC and Vebe test is generally used to evaluate the consistency of a RCC mixture.[13]

2. CASE STUDY

In this study, data of Dyraaba RCC gravity dam has been used. This project is located near bandarawela, Uva province, Sri Lanka (figure.1). This dam is designed for the aim of providing agriculture and water transmission to underground hydropower plant powerhouse through a conveyance tunnel with length of 15.5 Km. Dam reservoir capacity is almost 0.970 MCM, and total concrete volume for dam body was about 105000 cubic meters. The installed capacity of the powerhouse is 2x60 MW.

The applied mix design of RCC that is used in dam body is the mixture of water and cement (w/c ratio is equal to 0.57) and fine and coarse aggregates (MSA is equal to 50 mm) as shown in Table 1.

Table 1 : RCC mix design

Mix Design ID	Concrete Class	Cement (kg)	Pozzolan	W/C	Sand		Gravel	Admixture
		(kg)	(kg)		0-5mm	5-25mm	25-50 mm	(kg)
RCC190-5	C11	95	95	0.57	810	658	746	1.52

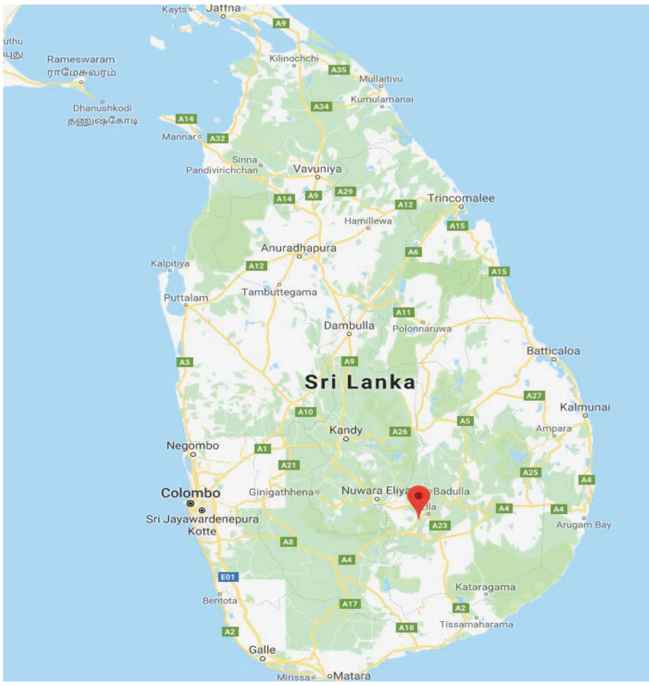

Figure 1 . Location of Dyraaba dam in Sri Lanka

Table 2 : mix design features

Mix Design ID	Final Age test (days)	Unit Weight (kg/m3)	Vebe time (sec)	Location	Initial Setting Time (hr)
RCC190-5	180	2514	10~30	dam body	8~20

The determined proportions of RCC mix design are chosen due to optimize both the performance criteria and the cost of mixture. Selected mix design for RCC dams and hydraulic structures should satisfy several requirements, includes strength requirements in different loading conditions, thermal properties, and durability and workability issues. As it is mentioned before, in this study, the impact of Vebe time, density and compressive strength of RCC is used to evaluate and predict impermeability of Dyraaba dam's body.

Vebe consistency is an indicator of the workability of RCC and is determined by ASTM C 1170,"Standard Test Method for Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table". In this test, a sample of RCC is vibrated under a 50-pound surcharge until it is fully consolidated, the time required to consolidate the sample is a function of the relative workability of the RCC and is called the Vebe time.

Absorption, porosity and density of RCC cores are determined according to ASTM C642 (Standard Test Method for Density, Absorption and Voids in Hardened Concrete).The density and volume of voids of fresh RCC will influence the performance of the hardened concrete. The density of the materials and the degree of consolidation govern the density of RCC. The density of RCC is normally assumed at about 2400 kg/m^3 without entrained air and with the volume of voids between 0.5 and 1.5 percent. If a lift of RCC is not fully consolidated, the percent voids along lift joints may reach 5 to 10 percent, resulting in seepage and poor bonding. In this research, density of all manufactured unhardened RCC specimens according to ASTM C 1170 and compare with the maximum density obtained from modified compaction test (ASTM D 1557).

Figure 2 : RCC core

Permeability of RCC mass is one of the most important parameters in RCC dams. This is mainly due to the direct relationship between these parameters and problems such as water leakage through the dam body, the pore water pressure, the stability in freezing and thawing cycles and also in the durability requirements Depth of water penetration in obtained RCC cores from dam body has been determined from BS EN 12390-8 (Depth of penetration of water under pressure).

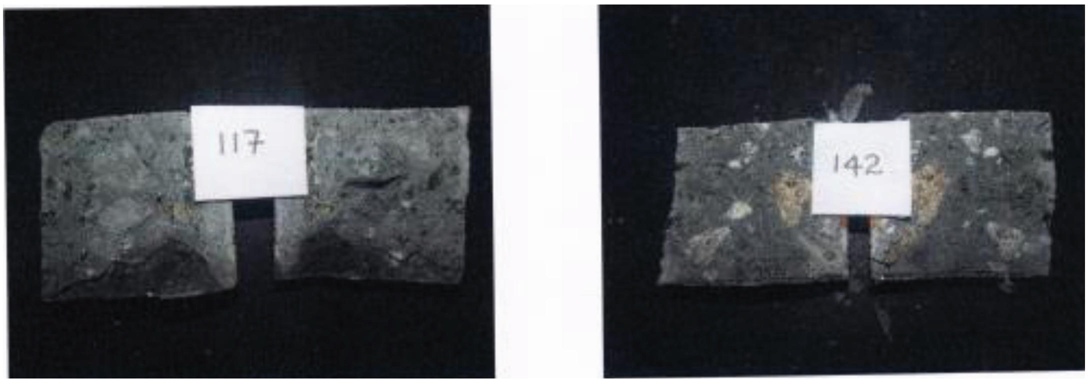

Figure 3 : Test specimens after splitting into halves

Compressive strength is normally specified for most RCC structures. Though it may not be the governing design criterion, compressive strength is a good indicator of mixture composition and variability. Compressive strength and elastic properties are governed by the water to cementitious material [W/(C+P)] ratio of the mixture and the degree of compaction. According to project technical specification, compressive strength tests based on ASTM C 39 have been executed on 8 specimen in different ages (7, 28, 90 and 180 days) and all lab concrete specimens have been capped using sulfurous mortar as required by ASTM C 617.

3. METHOD

RCC impermeability is affected by various external factors. It could be investigated different empirical or computational modeling, statistical techniques and artificial intelligence approaches. Here we concentrated on statistical methods and regression models in order to find out the relation of mentioned properties with impermeability of layers of RCC. In addition to the acceptable accuracy of these kind of models, their speed is one of the advantages of this technique.

In this paper, linear, exponential, logarithmic and multiple linear regression models have been used in order to find the relationships between various properties of hardened and unhardened RCC.

In statistics, linear regression is a linear approach to modeling the relationship between a scalar response (or dependent variable) and one or more explanatory variables (or independent variables). The case of one explanatory variable is called simple linear regression. For more than one explanatory variable, the process is called multiple linear regression. Every value of the independent variable x is associated with a value of the dependent variable y. The population regression line for p explanatory variables x1, x2, … , xp is defined to be $y = \beta 0 + \beta 1\ x1 + \beta 2\ x2 + ... + \beta p\ xp$.

An exponential regression is the process of finding the equation of the exponential function that fits best for a set of data. As a result, we get an equation of the form $y=a.ex$ where $a \neq 0$. Just as with exponential functions, there are many real-world applications for logarithmic functions. As with exponential models, data modeled by logarithmic functions are either always increasing or always decreasing as time moves forward. Again, it is the way they increase or decrease that helps us determine whether a logarithmic model is applicable. Logarithmic functions increase or decrease rapidly at first, but then steadily slow as time moves on. By reflecting on the characteristics we've already learned about this function, we can better analyze real world situations that reflect this type of growth or decay. When performing logarithmic regression analysis, we use the form of the logarithmic function most commonly used on graphing utilities, $y=a+b.\ln(x)$.

The relative predictive power of a regression model is denoted by R2. The value of R2 varies between 0 and 1. The more close the value is to 1, the more accurate the model is.

4. RESULTS

In this research, Matlab curve fitting tools has been applied in order to find out the relation between various parameter. First of all, the effect of porosity on water absorption and density of RCC cores has been investigated. As it is shown in figure 4(a), there is a direct relationship between porosity and possibility of water absorption and figure 4(b) illustrates that less void in concrete will led to reach more density.

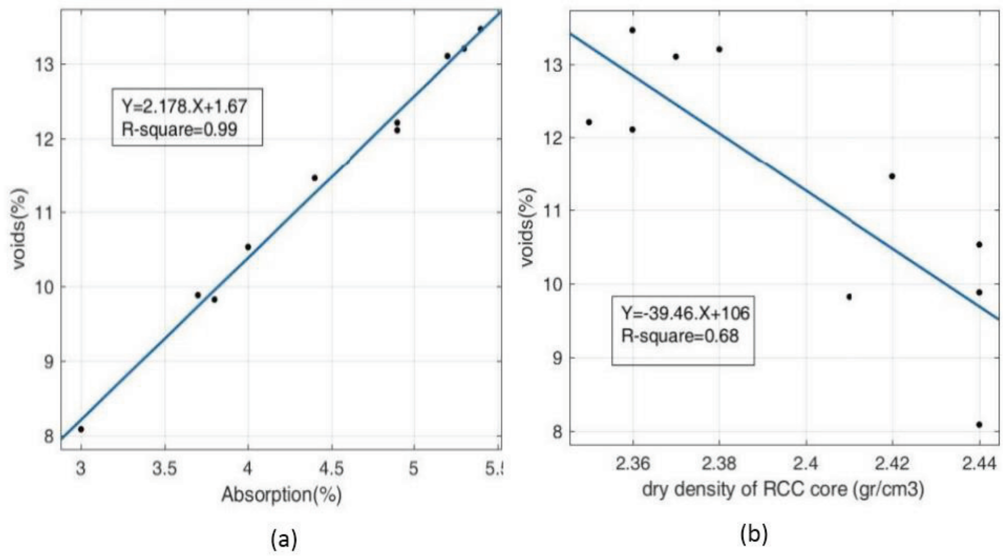

Figure 4 : (a) Relation between porosity and water absorption. (b) Relation between porosity and dry density of RCC cores.

Secondly, the relation between density and compressive strength of RCC specimens has been checked. Following graphs (Figure 5) outlines that compressive strength is an Increment function of density and used curve fitting tool fit an exponential function with acceptable correlation coefficient for each age.

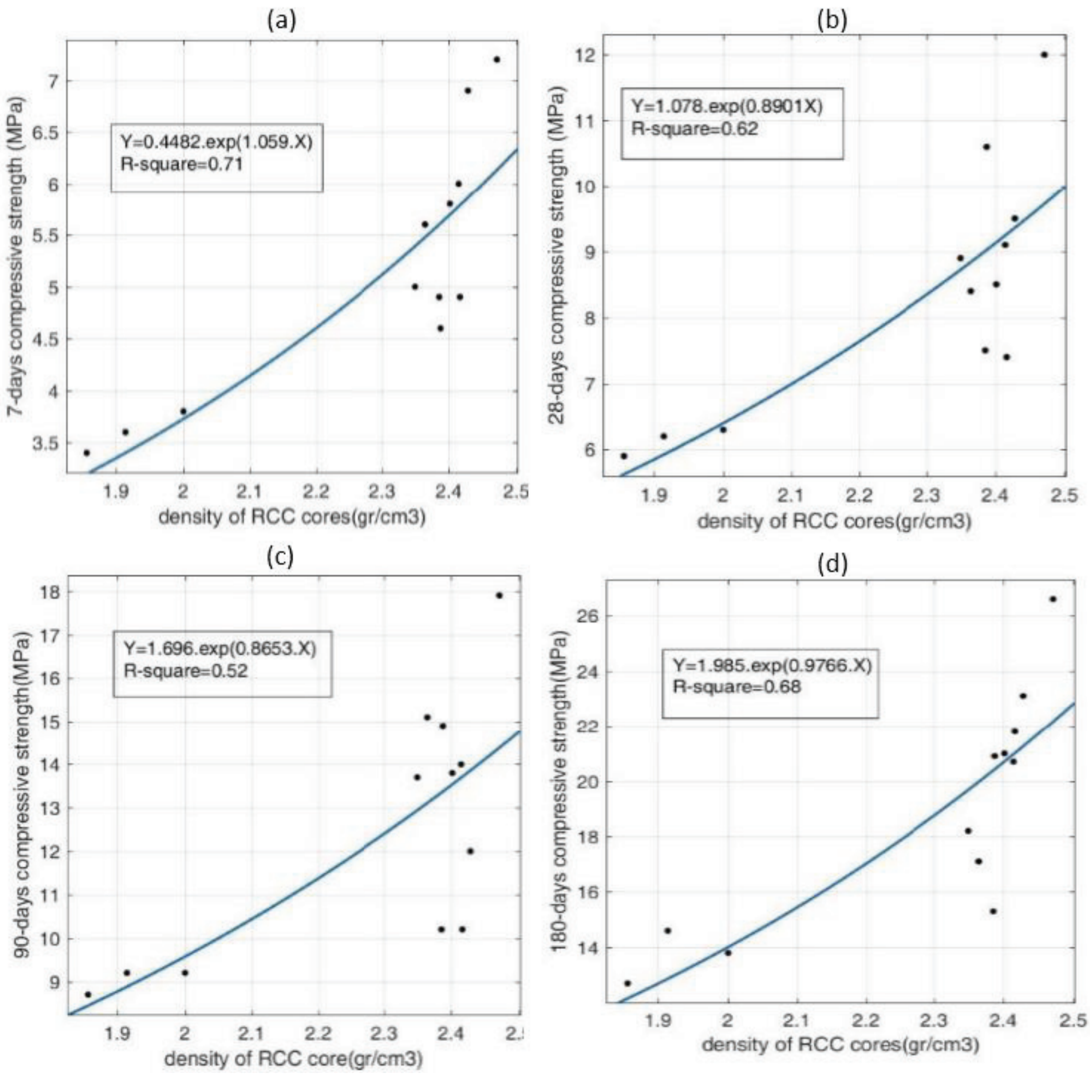

Figure 5 : Relation between density of RCC cores and compressive strength in different ages

Relations and graphs that are shown in figure (4) and figure (5) are logically compatible with our knowledge about roller-compacted concrete and prove the accuracy of our experiments.

According to above explanations, impact of three property of RCC on its permeability are chosen to be studied. In figure (6) fitted curve for relation of Vebe time, density and compressive strength and their correlation coefficient are provided. Correlation coefficient is the analysis criterion for fitting different functions. Data analysis shows that there is no significant relation between Vebe time and average depth of penetration (figure 6a). However, density and compressive strength remarkably effect on the depth of penetration.

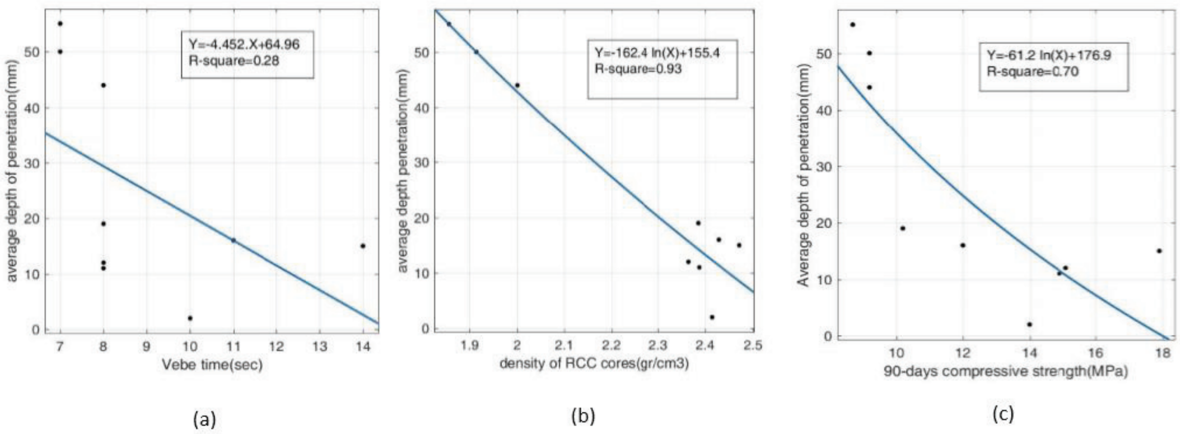

Figure 6 : Relation of average depth of penetration with Vebe time, density of RCC cores and compressive strength

Developed equation in figure (6b) can be used for estimation of average depth of penetration as a criterion for permeability by means of density of RCC cores.

$$y = -162.4 \times \ln(x) + 155.4 \quad , R^2 = 0.93 \tag{1}$$

Where "y" is average depth of penetration (mm) and "x" is density of RCC cores (gr/cm3).

And developed equation in figure (6c) can be used for estimation of average depth of penetration as a criterion for permeability by means of 90-days compressive strength.

$$y = -61.2 \times \ln(x) + 176.9 \quad , R^2 = 0.70 \tag{2}$$

Where "y" is average depth of penetration (mm) and "x" is 90-days compressive strength (MPa).

According to results, it is logical to predict the amount of permeability by use of a multi-variable function. Because the obtained correlation coefficient in figure (6 b and c) are high enough to use multiple linear regression in order to fit an appropriate curve and estimate average depth of water penetration. So by use of Matlab curve fitting tools following equation has been developed. (figure7)

$$z = 164.2 - 9.041 \times \ln(x) - 145.4 \times \ln(y), \quad R^2 = 0.94 \tag{3}$$

Where "Z" is average depth of penetration (mm), "x" is 90-days compressive strength (MPa) and "y" is density of RCC cores (gr/cm^3).

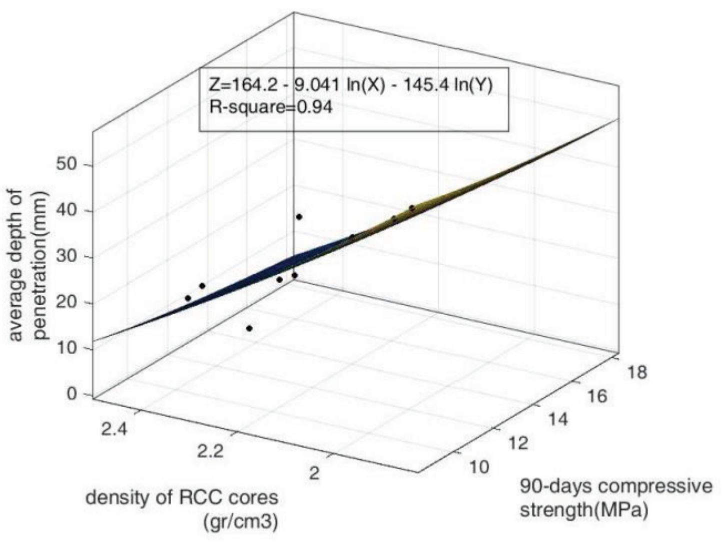

Figure 7 : Relation of average depth of penetration with density of RCC cores and compressive strength

5. CONCLUSION

1. RCC Permeability depends on properties such as consistency, compaction and strength. According to experiments the property with utmost importance is compressive strength, next one is density and the component with lowest impact between chosen properties is consistency that is expressed by Vebe time.
2. In some cases (about 5 percent of specimens), although the amount of density was acceptable, but test results showed high permeability. It obviously prove that there are other effective factor that are mainly executive troubles such as quality of compaction, distance of conveyance between batching plant and dam body, etc. that can significantly effect on permeability of dam body.
3. By means of developed equations, it is possible to predict the amount of permeability very soon and it can help to modify mix design, method of construction and any other related issues in order to reach acceptable results and save time, reduce costs and uncertainties.

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