Prediction of Permeability and Compressive strength for Pervious Concrete

K Pareek¹ and Y M Hong²
1 Student, Nanhua University, Chiayi County, Taiwan
2 Professor, Nanhua University, Chiayi County, Taiwan

E-mail: 10774107@nhu.edu.tw

Abstract. Due to characteristics of water infiltration and runoff reduction pervious concrete is becoming popular among many developed countries. The most important property of pervious concrete is its permeability and compressive strength. But it is seen that pervious concrete generally possesses low compressive strength which can be improved by various cementitious material. The aim of this research is to assess the use of silica fume, fly ash and YC819 on pervious concrete. Permeability and compressive strength test was conducted out of which compressive strength was conducted as per conventional ASTM method but permeability test was conducted by new method originated by authors. Furthermore, estimation of compressive strength using statistical regression analysis is attempted compared with model generated by different researchers. Replacement of cement by silica fume and fly ash are been done in 0 to 25% and the result showed increase in compressive strength of pervious mix by 15 to 20% whereas permeability was observed to be decreased by 3% in fly ash mixed pervious mix on the other hand silica fume reduces the permeability by 5% as compared to conventional pervious mix. In accordance with data obtained for compressive strength prediction an empirical equation was found whose R² was 0.67. When the models like Abrams, ACI, JSCE, Zain were applied and compared for prediction of compressive strength result showed that models do not predict the compressive strength as the different characteristics were neglected therefore it’s better to use Artificial Neural Network (ANN) as compared to statistical regression model for prediction.

1. Introduction
Comprised of cement, water, aggregate and some additives in form of chemical and mineral admixtures concrete is the second most widely used substance after water on planet earth. The reason behind the concrete being the founding material for the modern development lies in the fact of its abundance in nature (limestone), durability, thermal mass and ability to retain storm water etc. There are several factors on which quality of concrete is determined such as water cement ratio, coarse aggregate size, fine aggregate size, curing condition and etc. [1,2].

Concrete is used in construction because of its compressive strength which is very high as compared to its tensile strength. Generally determined by cubes or cylinder under 28 days curing. In case of cylindrical specimen 150 mm diameter and 300 mm height a high load is applied longitudinally under uniaxial compression loading which is then divided by loading area to get compression capacity [3]. On the other hand, permeability is defined as the movement of fluid through a porous medium under an applied pressure head is the most important property of concrete governing its long-term durability. Permeability of concrete, in turn, is influenced by two primary factors: porosity and interconnectivity of pores in the cement paste and micro-cracks in the concrete, especially at the paste–aggregate interface. Porosity and interconnectivity are controlled for most part by the w/c ratio, degree of hydration, and the degree of compaction [4]. In any type of concrete construction and engineering judgement prediction of
compressive strength and permeability is becoming a necessary requirement. In last couple of decade compressive strength prediction has reached new stage with application of SPSS and ANN. Statistical Package for the Social Sciences shortly known as SPSS is a user friendly yet powerful software package used for analysing, manipulating and presenting data which is mostly used in behavioural and social sciences. Among the different forms of SPSS programs available the core program is known as SPSS Base which is further extended into multiple modules on the basis of varying statistical and data entry capabilities [5].

In this study Regression Model SPSS is used as it helps to form a relationship among the variable input. Moreover, it helps to understand the variable change in dependent value keeping some independent value fix and other changeable. But in most of the cases, the estimation target is a function of the independent variable known as the regression function. The aim of this study is to determine the compressive strength and permeability of pervious concrete mix and then to analysis the effect of different parameters like water, cement, coarse aggregate etc. on compressive strength by using multiple linear regression. At last an empirical equation is obtained based on the analysis result which is used to compare with actual results. The empirical formula is then used to compare the results of other researchers stating its applicability.

2. Experimental work

The specific and detailed sets of data should be provided to SPSS to predict the permeability and compressive strength of pervious concrete mix. In this study 915 concrete specimens were used out of which some concrete specimens are prepared at Nanhua University laboratory and some of data set are obtained from Professor ChenYeh from Chung-Hua University [6]. Reason for adding more data correspond to fact that geographic position of both the places are nearly same as well as extraction of materials are quite similar. The specimens were constructed in cylindrical shape with a diameter 15 cm and height of 30 cm. Table 1 depicts the characteristics of concrete data used in the experiment and table 2 depicts the number of patterns used for SPSS modelling. Details of basic materials used is shown below:

- **Cement**- Ordinary Portland type-1 which is available in local Taiwanese market is used. The bulk density of cement type used is 1257 kg/m³.
- **Coarse Aggregate**- 10 mm and 20 mm are the two type of CA were used in this study which are available in Taiwanese local market. The value of bulk density of CA used is 1623 kg/m³.
- **Water**- Potable water was used for casting of all the specimens
- **Fly Ash**- Fly ash was obtained from Guitian Lab Doliu, Taiwan. Fly ash was used to replace various percentage of weight proportions of cement. The specific gravity of fly ash is 2.7.
- **Silica fume**- It was procured from Guitian lab, Taiwan. Silica fume was also used to replace various percentage of weight percentage of cement. The specific gravity of silica fume is 2.2

| Table 1. Characteristics of concrete data |
|------------------------------------------|
| Serial Number | Parameters      | Minimum | Maximum | Unit   |
| 1             | Age            | 7       | 365     | days   |
| 2             | Blast Furnance Slag | 0       | 359.4   | kg/m³  |
| 3             | Cement         | 102     | 540     | kg/m³  |
| 4             | Coarse Aggregate | 801     | 1299.1  | kg/m³  |
| 5             | Compressive strength | 7.51     | 82.6    | MPa    |
| 6             | Fine Aggregate | 594     | 992.6   | kg/m³  |
| 7             | Fly Ash        | 0       | 483     | kg/m³  |
| 8             | Silica Fume    | 0       | 483     | kg/m³  |
| 9             | Super Plasticizer | 0       | 32.5    | kg/m³  |
| 10            | Water          | 72.2    | 247     | kg/m³  |
Absolute volume mix method was used to find out the concrete mix proportions. It is an accurate method for making concrete specimen occupying unit volume using specific gravity for all the ingredients used. Compression strength test was conducted on the basis of ASTM C39 at the age of 28 days of curing and was measured through Universal testing machine. Table 3 depicts the characteristics of specimens constructed and used for regression analysis.

Table 2. Number of patterns used in Regression Modelling

| Serial number | Number of patterns | Compressive Strength (MPa) |
|---------------|--------------------|---------------------------|
| 1             | 112                | 7 to 20                   |
| 2             | 185                | 20 to 30                  |
| 3             | 239                | 30 to 40                  |
| 4             | 164                | 40 to 50                  |
| 5             | 116                | 50 to 60                  |
| 6             | 58                 | 60 to 70                  |
| 7             | 36                 | 70 to 83                  |

Specimens prepared at Nanhua University laboratory were subjected to Permeability measurement using storm water pipe having diameter of 15.1 cm and having 40 cm height as shown in figure 1 as a sample placement. In this test we pour 1 litre of water through sample and after 1 minute, we how water is retained on the base below. Same procedure is reiterated for 6 times until the reading get constant which indicate that all the unfilled air voids are full and the water flows only through voids interconnected voids of concrete. Sample picture of the setup made for calculation of permeability has been shown in figure 2. All test was done in accordance with IS 516 and table 2 below shows the value of average permeability recorded.

Figure 1: Permeability test setup
Figure 2: Cross sectional and side view of experimental setup (dimensions are in cm)

Table 3: Depicting the characteristics of specimens

| Aggregate size (mm) | Water cement ratio | Cement (kg/m³) | Aggregate quantity (kg/m³) | Water (kg/m³) | Admixture type | Admixture quantity | Sample Code |
|---------------------|--------------------|----------------|-----------------------------|---------------|----------------|--------------------|--------------|
| 20                  | 0.35               | 250.9          | 1299.09                     | 117           | Nil            |                    | M1           |
| 20                  | 0.40               | 250.9          | 1299.09                     | 100.75        | Nil            |                    | M2           |
| 10                  | 0.35               | 250.9          | 1272.18                     | 117           | Nil            |                    | M3           |
| 10                  | 0.40               | 250.9          | 1272.18                     | 100.75        | Nil            |                    | M4           |
| 20                  | 0.35               | 225.81         | 1299.09                     | 117           | Fly ash        | 25.09              | M5           |
| 20                  | 0.40               | 225.81         | 1299.09                     | 100.75        | Fly ash        | 25.09              | M6           |
| 10                  | 0.35               | 225.81         | 1272.18                     | 117           | Fly ash        | 25.09              | M7           |
| 10                  | 0.40               | 225.81         | 1272.18                     | 100.75        | Fly ash        | 25.09              | M8           |
| 20                  | 0.35               | 250.9          | 1299.09                     | 84.5          | YC819          | 32.5               | M9           |
| 10                  | 0.40               | 250.9          | 1272.18                     | 87.75         | YC819          | 13                 | M10          |
| 10                  | 0.35               | 250.9          | 1272.18                     | 104           | YC819          | 13                 | M11          |
| 20                  | 0.40               | 250.9          | 1299.09                     | 87.75         | YC819          | 13                 | M12          |
| 20                  | 0.35               | 250.9          | 1299.09                     | 104           | YC819          | 13                 | M13          |
| 10                  | 0.40               | 225.81         | 1272.18                     | 100.75        | Silica fume    | 25.09              | M14          |
| 10                  | 0.35               | 225.81         | 1272.18                     | 117           | Silica fume    | 25.09              | M15          |
### 3. Regression analysis and performance criteria

Statistical Regression Analysis is a statistical tool used to predict the relationship between a dependent variable and an independent variable. This relationship is generally expressed through statistical model equation through which we can predict the future value of response variable using regression variable, note that we generally use statistical method when there is continuous dependent variable and number of independent variables. But these parameters are estimated so that a measure of fit is optimized having values as close as possible to real system [7,8]. There are generally two type of regression analysis model linear regression model and multiple regression model. Linear regression is most common form of regression and most common type of linear regression is least square regression. In this we basically use two sets of given values to predict the futuristic value of dependent. $R^2$ is measure of association which represent the variance in value of dependent variable that can explained by knowing the value of independent variable. Another type of regression analysis model is multiple regression model which is an extension of linear regression. Multiple regression allows additional factors to enter the analysis separately such that effect of each is analysed [5,9]. The aim of using multiple regression is to enable the researcher to assess the relationship between more than three independent variables with dependent variable. Value of $R^2$ generally varies from 0 to 1.

Statistical regression analysis is a powerful tool to predict the compressive strength of concrete considering the materials input. The origin of predicting compressive strength starts with Abrams law which stated that increasing the water cement ratio is inversely proportional to compressive strength [10]. Abrams law served as base research for many researches such as Zain and Zhang. American Concrete Institute also gave an equation stating the relation between compressive strength and water cement ratio [11]. But both Abrams law and ACI equation didn’t mention about time of curing, use of chemical and natural admixture. Zain et al also used multiple regression model to predict the compressive strength of high performance concrete and yielded an excellent correlation coefficient of 99.99% accuracy of concrete specimen using mineral admixture like silica fume (SF) and fly ash (FA) at the different ages of curing (3,7,14, 28 and 81) [12]. In 2011 Zhang et al. stated that prediction of compressive strength by varying the time period from 7 to 365 days [13]. JSCE (2012) stated that prediction of the compressive strength using the minerals admixtures and time period at the same time but in specified series of dates [14]. In table 4 comparative analysis has been done depicting the empirical equations given by authors and institutes whereas table 5 and table 6 represent the correlation coefficient founded by authors and institutes.

In this study an attempt is made to predict the compressive strength by varying the mineral admixtures concentration with time as a function of compressive strength. Multiple linear regression is used to predict the compressive strength of cylindrical specimens. The result of the analysis is the empirical formula between the compressive strength and various parameter. The various parameters are the cement concentration, water concentration, silica fume, blast furnace slurry, fly ash, coarse aggregate, fine aggregate and w/c ratio. By using SPSS software version an empirical formula between the compressive strength of concrete ($f_{cm}$) as dependent variable and cement (C), water (W), fine aggregate (fine agg.), coarse aggregate (Coarse agg.), blast furnace slag (BFS), fly ash (FA), super

| 20  | 0.40 | 225.81 | 1299.09 | 100.75 | Silica fume | 25.09 | M16 |
|-----|------|--------|---------|--------|-------------|------|-----|
| 20  | 0.35 | 225.81 | 1299.09 | 117    | Silica fume | 25.09 | M17 |
| 10  | 0.40 | 250.9  | 1272.18 | 72.15  | YC819       | 28.6 | M18 |
| 10  | 0.40 | 188.11 | 1272.18 | 100.75 | Fly ash     | 62.79| M19 |
| 10  | 0.35 | 188.11 | 1272.18 | 117    | Fly ash     | 62.79| M20 |
| 10  | 0.40 | 188.11 | 1272.18 | 100.75 | Silica fume | 62.79| M21 |
plasticizer (SP) and age (curing age) as an independent variable. Analysis results also known as the $R^2$ value. $R^2$ is always between 0 and 100%.

**Table 4**: Equations to predict the compressive strength of concrete cylinder where $f_{cm}$ is average compressive strength of the concrete cylinder (150mmx300mm)

| Author | Formula proposed | Coefficient values and limitations |
|--------|------------------|-----------------------------------|
| Abram  | $f_{cm} = \frac{A}{B^w/c}$ | The constants A and B are 96 MPa and 7, respectively. w/c ratio should be between 0.3 and 1.2 |
| American Concrete Institute Manual of Concrete Practice (ACI2000-I) | $f_{cm} = 117.07 \cdot e^{-2.572 \cdot w/c}$ | The w/c ratio and cement content of the concrete mixes are limited to 0.41–0.82 and 300–360 kg/m3, respectively. The equation was adapted from the results of the table given in the specification with $R^2 = 0.996$ |
| Zhang (2011) | $f_{cm} = \left( \frac{22.5C}{W} - 12.1 \right) \left[ (1.05r + 0.15)\ln t - 2.77r + 0.79 \right]$ | $r=$fly ash upto 50% replacement and $t$ indicate time $(7<t\leq365)$ |
| Zain (2009) | $f_{cm} = a_0C^{a_1}W^{a_2}Fa^{a_3}Ca^{a_4}SF^{a_5}\rho^{a_6}FA^{a_7}S^{a_8}$ | The value of the different constant varies according to number of day |
| Japanese Society of Civil Engineering (JSCE) | $f_{cm} = a \left( \frac{C}{W} + K \cdot \frac{F}{W} \right) + b$ | Constant a, K, b whose values are shown in table, where replacement limit for fly ash is 40% |

**Table 5**: Correlation coefficient between compressive strength at different stage and selected variables for model proposed by Zain

| Variable | 3 days CS | 7 days CS | 14 days CS | 28 days CS | 81 days CS |
|----------|-----------|-----------|------------|------------|-----------|
| Ca       | -0.99     | -0.99     | -0.99      | -0.99      | -0.99     |
| Fa       | -0.98     | -0.98     | -0.99      | -0.99      | -0.98     |
| C        | 0.92      | 0.89      | 0.91       | 0.91       | 0.85      |
| SF       | 0.22      | 0.28      | 0.22       | 0.2        | 0.36      |
| FA       | 0.1       | 0.09      | 0.12       | 0.12       | 0.08      |
| W        | -0.99     | -0.98     | -0.99      | -1         | 0.97      |
| S        | 0.59      | 0.57      | 0.56       | 0.56       | 0.58      |
| $\rho$   | 0.26      | 0.2       | 0.24       | 0.25       | 0.13      |
Table 6: JSCE equation correlation coefficient value

| Age (days) | K   | a    | b    |
|-----------|-----|------|------|
| 7         | 0.253 | 24.016 | -16.756 |
| 28        | 0.390 | 28.938 | -15.616 |
| 91        | 0.549 | 32.243 | -13.939 |

4. Results and discussion

We check the permeability of plain pervious concrete cube 1000 ml water which is passed through the voids of the plain pervious concrete cube and the water is retained to another pan that stored it and then measured. Eight times the reading were taken with the gap of 3 min and average of which is shown in table below. The universal testing machine is used for testing the compressive strength of concrete according to ASTM C39M/2003 for cylinders \( f_{cm} \) measuring 150mm x 300mm. Testing was carried out at 28 days and at age of testing.

Result obtained from the above experiments shows that replacement of Silica fume and fly ash have negative effect on permeability but have affirmative effect on the compressive strength of mix. With increase in replacement of fly ash from 0% to 25% there was 3% decrement seen in the permeability of the mix on the other hand compressive strength of the mix increases by 15%. When Silica fume is used as admixture compressive strength of mix increases upto replacement of 25% but further more increase in silica fume concentration reduces the permeability by 5% as compared to conventional mix. While permeability reading doesn’t varied that much. When YC819 is used as the admixture the setting time of concrete mix increases but the permeability of mix remains but compressive strength of mix was observed to decreased with increase in concentration of YC819. Aggregate size have also deep effect as with 20mm aggregate permeability is more compared to 10 mm based concrete mix can be observed from figure 3. Based on above results, we found that use of silica fume should be confined to 5% when mixed in pervious concrete as it enhances the compressive strength but decreases the permeability of the mix. For fly ash replacement should be done upto 10% as it increases compressive strength and permeability also remains constant compared to 0% mix.

The data obtained from compressive strength test and from prof Yeh are used for mathematical modelling by using multiple linear regression method. The purpose of mathematical modelling was to get an empirical formula to establish the relationship between compressive strength and variables like cement, water, coarse aggregate, fine aggregate, fly ash, super plasticizer, age of curing and blast furnance slag. The coefficient of determination \( (R^2) \) is the proportion of the total variation in \( f_{cm} \) explained by the regression of \( f_{cm} \) on \( (X_1 \ldots X_8) \) and \( R^2 \) ranges from 0 to 1 i.e. when the estimated regression allows none of variation in \( f_{cm} \) to the stage when all points lie on the regression line. Analysis was done by using SPSS program version 22. The empirical formula predicting the compressive strength is as below:

\[
f_{cm} = C + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_4 + A_5 X_5 + A_6 X_6 + A_7 X_7 + A_8 X_8
\]

Where \( f_{cm} \) is the compressive strength of concrete in N/mm\(^2\), \( X_1 \) is cement in kg/m\(^3\), \( X_2 \) is blast furnance slag in kg/m\(^3\), \( X_3 \) is fly ash in kg/m\(^3\), \( X_4 \) is water kg/m\(^3\), \( X_5 \) is super plasticizer in kg/m\(^3\), \( X_6 \) is coarse aggregate in kg/m\(^3\), \( X_7 \) is fine aggregate in kg/m\(^3\), \( X_8 \) is age in days respectively.
Figure 3: Permeability value comparison

Through obtained empirical equation for test data comparison of estimated values with experimental compressive strength value have been given in figure 4. Complete data set were then used to testify the equation suggested by different researchers. The original method of Abrams, ACI and modified method of JSCE, Zhang & Zain cannot accurately predict the compressive strength of cylinder specimen as the original method uses only water-cement ratio as an influencing factor and on the other hand modified method consider different factors but didn’t uses the all the factor at the same time. In other words, the estimated strength of concrete based on the quality of cement paste is not accurate, and the relationship between the actual and calculated strength for all the original models is poor when only w/c (with and without considering the volume of aggregates to the cement content) is considered as an influencing factor. Even if empirical equation given have better $R^2$ of 0.80 or even 0.90 it is not the same for other researcher data. Figure 5 compares the empirical formula given by researchers and it can be observed from the figure that these empirical equations cannot accurately predict the compressive strength accurately due to reasons mentioned above. Therefore, it is suggested to use different computing approach such as ANN for predicting the compressive strength.

Figure 4: Comparison of result between experimental value and predicted value
5. Conclusion

For achieving high permeability and porosity pervious concrete are favoured as compared to any other concrete type. Pervious concrete has 15 to 30% more pores as compared to conventional concrete but that lowers its compressive strength many folds. Therefore, conventional pervious concrete mix requires some modifications like addition of admixtures like fly ash, silica fume and YC819. When fly ash, silica fume and YC819 were used following conclusions can be made considering permeability as main factor:

- Replacement of fly ash should be done up to 15% as it increases the compressive strength and doesn’t alter the permeability of the mix compared to conventional pervious mix.
- Application of silica fume should be limited to 5% as it increases the compressive strength but decreases the permeability.
- YC819 have nearly no observed effect on permeability on pervious mix but decreases the compressive strength of mix.

Empirical equation obtained from regression analysis shows great potential but not at required level as $R^2$ of the equation was 0.67 only which shows huge gap between predicted and actual value of compressive strength. When the empirical equation of different researchers was used huge variation of compressive strength were recorded. Therefore, it is suggested to use artificial neural network (ANN) for predicting the compressive strength.

6. References

[1] S SP 1993 Recent trends in the science and technology of concrete, concrete technology, new trends, industrial applications Proc. of the international RILEM workshop, London, E & FN Spon, pp. 1–18.
[2] B HH 1981 Densified cement/ultrafine particle based materials The second international conference on superplasticizers in concrete, Ottawa
[3] Bhanja S and Sengupta B 2002 Investigations on the compressive strength of silica fume concrete using statistical methods Cement and Concrete Research, vol. 32, pp. 1391-1394
[4] Banthia N, Biparva A and Mindess S 2005 Permeability of concrete under stress Cement and Concrete Research vol. 35, pp 1651–1655
[5] Pitroda J Prediction of strength for fly ash cement concrete through soft computing approaches International Journal of Advance research in engineering, Science and management (IJARESM), vol. 1, pp 1-11
[6] Yeh I.-C. 1998 Modeling of strength of high performance concrete using artificial neural networks Cement Concrete Research vol. 28(12), pp 1797–1808
[7] Chopra P Sharma R K and Kumar M 2014 Regression Models for the Prediction of Compressive Strength of Concrete with & without Fly ash *International Journal of Latest Trends in Engineering and Technology (IJLTET)*, Vol. 3 Issue 4, pp 400-406

[8] Maruthachalam D, Rajalaxmi R K and Vishnuram B G 2012 Statistical Modelling of Fiber Reinforced High Performance Concrete *International Journal of Scientific & Engineering Research*, Vol 3 No.6, pp.1-5

[9] Deshpande N, Londhe S and Kulkarni S S 2013 Modelling compressive strength of recycled aggregate concrete using neural networks and regression, *Concrete Research Letters*, Vol. 4 No.2, pp.580-590.

[10] Abrams, 1919 L.D. Properties of Concrete, 3rd ed.; Pitman Publishing Ltd.: London, UK

[11] ACI 2000-I. ACI Manual of Concrete Practice 2000, Part 1: Materials and General Properties of Concrete; American Concrete Institute (ACI): Farmington Hills, MI, USA

[12] Zhang W, Yoshituke I and Saitoh T 2011 Proposal of a Simplified Prediction Formula for Compressive Strength of Fly Ash Concrete *Advanced Materials Research* Vols. 287-290 pp 1201-1208

[13] Zain M F D and Abd S M 2009 Multiple regression model for compressive strength prediction of high performance concrete *Journal of Applied Sciences* Vol. 9(1) pp 155-160.

[14] Japan Society of Civil Engineers (JSCE) 2009: New Utilization Technologies of Fly Ash Concrete Suitable for Recycle Oriented Society-Recommendations for Design and Construction of Fly Ash Concrete (Draft), Concrete Library 132, pp.83-87.