The Interrelationship between the Methods used to Determine the Workability of Concrete

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Abstract. Workability is one of the factors that affect concrete strength and durability in addition to the cost of labor and the appearance of the final product. It is a vital feature of the concrete that must be measured properly to ensure the quality of concrete. This paper presents a method for predicting equations for workability of concrete and correlation between the workability tests by using Pearson correlation coefficient. The results show that the developed model is accurate and it can be used for prediction of the workability parameters with a high degree of accuracy. Based on statistical analysis, the correlation was significant at the 0.01 level (2-tailed) between the workability of concrete tests. Regression equation relating compacting factor and slump was based on nonlinear general equations (C = 0.5371S^0.1204) and also nonlinear equations were found between Vebe and slump tests (V = 8.0689e^{-0.0175x}).

Keywords. Workability, Concrete, Compacting factor, Slump factor.

1. Introduction
The properties of fresh concrete that determine workability are consistency, compatibility and mobility. Consistency is the measure of fluidity while mobility is the ability of new concrete to flow into the molds. Compatibility is the ease with which air is trapped, and voided. For new concrete to be stable, it must maintain its regularity which also depends on its consistency and cohesion [1]. Different results predict equations and relationships for workability of concrete. Agrawal and Sharma [2] used Artificial Neural Networks to estimate the slump in concrete. They used data obtained from batching plant. The (MSE) and (R²) were 0.05795 and 0.91845, respectively. They reported that the model could give optimum performance or could predict any mix ratios as long as the type of cement, additives (in particular, super plasticizers) and the combination of concrete components are the same.

Thaker and Arora [3] used the cone slump test and the small flow table test to understand the suitability of the test for low to high workable mixtures. A different cement paste with varying w/c were used. They reported that it was not possible to find a correlation between the two tests covering the entire range of workability. Nhat and Anh [4] proposed a model for concrete slump prediction based on Least Squares Support Vector Regression. This model was used for nonlinear mapping between mixer components and slump values. The results show that the model is able to accurately predict the slump of concrete. Regression analysis and artificial neural network (ANN) models were used to evaluate concrete slump. The results show that ANN is an effective method for nonlinear
modeling and its results are more significant than models based on the other traditional regression analysis [5][6][7][8]. Wei et al. [9] used the Pearson Correlation Coefficient to measure the relationship between mechanical properties, including (silica, and steel fiber content). They reported that the fine content of materials (silica fume) and fiber volume fraction were positively correlated with compressive strength and tensile strength respectively. In addition, fine content of materials was negatively related to the wear resistance. They also reported that the beneficial effect of adding silica was more pronounced on the compressive strength due to an increase in Pearson's coefficient. This work aims to predict equation for workability by using statistical analysis SPSS, and to find the correlations between workability tests by using Pearson correlation coefficient.

2. Test methods

2.1. Slump test
The device consists of a metal cone open from the top and the bottom. The size of the internal diameter at the base is 200 and 100 mm at the top. This device is usually supplied with a handle and foot cutter. The cone is filled with concrete in the form of three layers and compressed 25 times by a 16 mm rod for each layer. Next, the metal cone is raised, leaving the concrete sample behind, which is lowered by gravity.

2.1.1. Advantages. The equipment used is inexpensive and easy to carry and maintain. In this test, no digital processor is needed after obtaining the results. This test is considered suitable for many operators on different construction sites around the world.

2.1.2. Disadvantages. It is hard to develop a theoretical test model that can be used to analyze the test results in terms of basic rheological characteristics.

2.1.3. Standardization. ASTM C 143-78 [10].

2.2. Vebe test
This test is used for measuring the time required for a concrete block to change from a cone shape to a cylinder shape by means of vibrations.

2.2.1. Advantages. The Vebe test is the only method used for assessment of low workability, dry, and zero slump fresh concrete mixes which is not restricted to its country of origin only. The apparatus is compact and well suited for both laboratory and precast concrete factory use. The test results are obtained directly, without any additional processing.

2.2.2. Disadvantages. The device is expensive and the test is able to differentiate only mixtures with extremely low workability.

2.2.3. Standardizations. BS EN 12350-Part 3:2000 [11], ASTM C1170 [12].

2.3. Compacting test
This test is acceptable for evaluating fresh mixes for medium workability. The preferred range of application is for mixtures that produce CF between 0.70 and 0.95. The standard device used can handle mixtures containing aggregates of maximum size of no more than 20 mm.

2.3.1. Advantages. The test provides some indication of the compatibility of a fresh mix.

2.3.2. Disadvantages. The size of the device is relatively large compared to other types of devices, which increases the cost and maintenance requirements.

2.3.3. Standardization. BS 1881: Part 103: 1983 [13]
3. Pearson correlation coefficient

It is a statistical formula that measures the strength relationships between variables. The Pearson correlation coefficient often referred to is the Pearson R test.

\[
R = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}}
\]

Where; \( R \) = Pearson correlation coefficient, \( n \) = number of test, \( x \) = variable, and \( y \) = variable.

3.1. Development of predictive equations for workability

3.1.1. Relationship between slump and compacting factor. The results of compacting factor and slump are presented in Table 1. SPSS were used to develop regression equation between compacting factor and slump as shown in Fig. (1)

![Figure 1. The relationship between slump and compacting factor.](image)

**Table 1.** Compactive factor and slump test.

| Slump (mm) | Compacting factor | Estimated value of Compacting factor |
|-----------|-------------------|-------------------------------------|
| 25        | 0.77              | 0.79                                |
| 40        | 0.85              | 0.837                               |
| 75        | 0.87              | 0.9                                 |
| 80        | 0.92              | 0.91                                |
| 100       | 0.94              | 0.935                               |
| 110       | 0.95              | 0.945                               |
| 150       | 0.96              | 0.981                               |
| 10        | 0.75              | 0.708                               |
| 20        | 0.78              | 0.77                                |
| 30        | 0.83              | 0.808                               |
| 50        | 0.86              | 0.86                                |
| 60        | 0.9               | 0.879                               |
| 100       | 0.92              | 0.935                               |
| 120       | 0.95              | 0.955                               |
| 15        | 0.75              | 0.744                               |
| 30        | 0.78              | 0.808                               |
| 35        | 0.83              | 0.824                               |
| 40        | 0.87              | 0.837                               |
| 70        | 0.905             | 0.895                               |
| 80        | 0.91              | 0.91                                |
Where, $y = \text{Compacting factor}$, $x = \text{slump (mm)}$, $a$ and $b$ are constants. From Fig.1, the predictive equation relating slump and compacting factor is as shown in the equations (2) as follows:

$$C = 0.5371S^{0.1204}$$

(2)

$R^2 = 0.9477$

3.1.2. Relationship between slump and Vebe tests. The results of slump and Vebe tests are presented in Table 2: The regression equation was based on nonlinear general equations using SPSS. The relationship between slump and Vebe was best fitted using equation (3) and is shown in Fig.2

**Figure 2.** The relationship between slump and Vebe time.

### Table 2. Slump and Vebe tests.

| Slump (mm) | Vebe time | Estimated value of Vebe time |
|------------|-----------|-----------------------------|
| 120        | 0.98      | 0.988                       |
| 100        | 1         | 1.4                         |
| 80         | 1.5       | 1.989                       |
| 70         | 2         | 2.37                        |
| 60         | 2.5       | 2.8                         |
| 50         | 3         | 3.36                        |
| 40         | 3.5       | 4.01                        |
| 30         | 4.5       | 4.77                        |
| 20         | 6         | 5.686                       |
| 17         | 8         | 5.99                        |
\[ y = ae^{-bx} \]

Where, \( y = \) Vebe time, \( x = \) slump (mm), \( a \) and \( b \) are constants. From Figure 2, the predictive equation relating slump and Vebe time is as shown in the equations (3) as follows:

\[ V = 8.0689e^{-0.0175x} \]  \hspace{1cm} (3)

\[ R^2 = 0.9029 \]

3.1.3. Relationship between compacting factor and Vebe tests. The results of compacting factor and Vebe tests are presented in Table 3. The regression equation was based on linear general equations using SPSS. The relationship between slump and Vebe was best fitted using equation (4) as in Figure 3.

| Compacting factor | Vebe time |
|-------------------|-----------|
| 1                 | 1         |
| 1.3               | 0.98      |
| 1.5               | 0.95      |
| 2                 | 0.9       |
| 3                 | 0.85      |
| 4                 | 0.8       |
| 4.7               | 0.78      |
| 6                 | 0.75      |
| 7                 | 0.72      |
| 8                 | 0.7       |
| 8.3               | 0.68      |

![Figure 3. The relationship between compacting factor and Vebe time.](image)
From Figure 3, the predictive equation relating compacting factor and Vebe time is shown in the (4) as follows:

\[ y = -0.0409x + 1.0022 \]  

\( R^2 = 0.9456 \)

Where, \( y \) = Vebe time, \( x \) = compacting factor

3.2. Correlations between workability tests by using Pearson correlation coefficient

From the tables (4, 5 and 6) we observe the following:

1. The correlation coefficient \( (r) \) is 0.845, which is interpreted as a large coefficient.
2. The \( p \)-value is less than 0.001

| Table 4. Correlation between slump and compacting factor. |
|--------------------------------|
| Slump            | Pearson Correlation  | Slump | Compacting factor |
| Sig. (2-tailed) | 1                     | .904** |
| N                | 32                    | 32    |

| Table 5. Correlation between slump and Vebe time. |
|--------------------------------|
| Slump           | Pearson Correlation  | Slump | Vebe time |
| Sig. (2-tailed) | 1                     | -.845** |
| N                | 21                    | 21    |

**. Correlation is significant at the 0.01 level (2-tailed).

| Table 6. Correlation between Vebe time and Compacting factor. |
|--------------------------------|
| Vebe time      | Pearson Correlation  | Vebe time | Compacting factor |
| Sig. (2-tailed)| 1                     | -.972**  |
| N              | 11                    | 11       |

**. Correlation is significant at the 0.01 level (2-tailed).

4. Conclusion
The conclusions of the study are as follows:

1) By using workability test, the slump flow, compacting factor and the Vebe test ranged from (10-150), (0.7-0.99) and (0.98-6.10) respectively.
2) By using Pearson correlation coefficient the \( (R2) \) Correlation Coefficient was found to be 0.845to 0.972. This proves clearly that the Pearson correlation coefficient is reliable and useful for developing correlations between workability tests.
3) Statistical analysis SPSS can be used by engineers to estimate the slump in concrete.
• A good correlation was observed between slump and Vebe. Compacting factor tests increase the slump leading to increase the compacting factor and decrease the Vebe test.

• Regression equation relating compacting factor and slump was based on nonlinear general equations ($C = 0.5371S^{0.1204}$) and also nonlinear equations was found between vebe and slump tests ($V = 8.0689e^{-0.0175S}$). In addition, the relationship between compacting factor and Vebe time was $V = -0.0409C + 1.0022$.

5. References

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