Available online at www.elixirpublishers.com (Elixir International Journal)

Civil Engineering

Elixir Civil Engg. 120 (2018) 51428-51431

Awakening to Reality

Elixir ISSN: 2229-712X

Modeling to predict the characteristics strength of concrete using Regression Analysis

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ARTICLE INFO

Article history:

Received: 12 June 2018;

Received in revised form: 17 July 2018;

Accepted: 27 July 2018;

Keywords

Concrete,

Concrete age,

Compressive Strength and

Simple Linear Regression.

ABSTRACT

Based on existing experimental data for compressive strength values of different concrete mixes in statistical analysis for the data gathered was conducted. The analysis revealed a model for predicting the compressive strength of concrete mixes at any age with the help of two constants X and Y that are a characteristic property of a concrete mix. The constant X is introduced as age of concrete, whereas, Y is introduced as compressive strength of concrete constant. One of the values of constants X and Y are defined for a concrete mix, the compressive strength at any age could simply be predicted without collecting data at that age. Performing trail concrete mixes (1:2:4 and 1:3:6), is the method used to define the two constant and simple linear regression was used to model the results. The simple linear regression model for mix ratio 1:2:4 and 1:3:6 (Y = 10.75327 + 0.26667X and Y = 8.8605 + 0.022714X) yielded values for the prediction of the compressive strength at different ages (7. 14. 21 and 28days). The mean compressive strength for the two mix ratios are 13.2N/mm^2, 14.7N/mm^2, 15.03N/mm^2, 19.07N/mm^2, and 10.8N/mm^2, 12.27N/mm^2, 12.07N/mm^2, 16.20N/mm^2, respectively. While the results for each age of concrete using regression model for the two mix ratios are 12.62N/mm^2, 14.49N/mm^2, 16.35 N/mm^2, 18.22N/mm^2 and 10.46N/mm^2, 12.04N/mm^2, 13.563N/mm^2, 15.22N/mm^2.From the above data, it was observed that there is a slight difference between experimental and analysed results i.e. the analysed results are slightly above or below the experimental results.

1.0 Introduction

Concrete is a construction material that is widely used throughout the world. The advantages of concrete include its low cost, availability for construction, workability, durability and convenient compressive strength, which makes it popular among engineers and builders (Abd et al., 2008). However, these advantages are strongly dependent on correct mixing, placing and curing. in the construction industry, strength is a primary criterion in selecting a concrete for a particular application. Concrete used for construction gains strength over a long period of time after pouring. The characteristic strength of concrete is defined as the compressive strength of a sample that has been aged for 28days (Hamid-Zadet et al., 2006).

Waiting 28 days to complete such a test would not suit the construction industry's need for speed, while neglecting the test would not satisfy the quality control process of concrete at large construction sites. Therefore, rapid and reliable prediction of the strength of concrete would be of great significance (Kheder et al., 2003). The ability to rely on model prediction would enable mix proportion adjustments in advance of placing and curing; this prediction – based technique would enable the avoidance of situations in which the concrete is too weak or unnecessarily strong and would facilitate a more economic use of raw materials and fewer construction failures, hence reducing construction costs.

Prediction of compressive strength for cement and concrete, therefore, has been an active area of research.

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A considerable number of studies have been carried out in this area. Many attempts have been made to obtain a suitable mathematical model that is capable of predicting the strength of concrete at various ages with acceptably high accuracy (Popovics et al., 1990). This study proposes a mathematical model to predict concrete strength using concrete characteristics from its mix proportion elements.

2.0 Materials and Methods

2.1 Regression Techniques

Regression techniques are used to discover relationship between a set of variablesThese techniques are used for identifying the patterns (relations) of independent and dependent variables, and dependent variables are termed as predictors. A regression technique typically try to relate some statistical measures like mean or average between the set of variables to identify the relationship between them.

2.2 Simple Linear Regression

Simple linear regression is the simplest regression analysis technique, where a line equation (Y = cX + cX + ….. cX + b) is used to relate the predictor variables (X, X, …. X) and response to the predictor (Y). Simple linear regression is a statistical technique that fits a straight line to set of (X, Y) data pairs. The slope and intercept of the fitted line are chosen so as to minimize the sum of squared differences between observed response values and fitted response Values, that is a method of ordinary least squares is used to fit a straight line model to the data.

2.3 Performance Measurements

The performance of regression based prediction techniques is carried in terms of errors in regression. Two such common errors in regression based prediction are Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE).

The Mean Absolute Error (MAE) is the average of the absolute value of the residuals (error). The MAE I very similar to the RMSE but is less sensitive to large errors. The MAE I calculated using the following:

MAE = In (Σ|yi – y^i|)

The Root Mean Squared Error (RMSE) is the square root of the average distance of a data point from the fitted line. The RMSE is calculated using the following:

RMSE = Σ(yi – y^i)2n

2.4 Modeling using Microsoft Excel Spreadsheet

The very first step of this study is to understand the strength gaining pattern of the concrete with age. For this reason, strength versus day curve will be plotted for every single set. If every curve follows a typical pattern, then Microsoft EXCEL spreadsheet tools will be used to plot the data. The second step of the study is to determine a general equation of this curve being plotted while the third step is to evaluate the value of constant X and Y.

2.5 Statistical Analysis for Production

The strengthening of concrete is a complex process involving many external factors. Multiple attempts have been made to model this process. A number of improved prediction techniques have been proposed by including empirical or computational modeling, statistical techniques and artificial intelligence approaches. Some models have used computational techniques such as finite element analysis, whereas others have used multivariable regression models to improve prediction accuracy. Statistical models are attractive in that, once fitted, they generate prediction much more quickly than other modeling techniques and are correspondingly simpler to implement in software.

There are many factors affecting concrete strength. Water to cement ration (w/c) consider being one of the most important factor in this respect. Many research works attempt to utilize this factor in models relating strength of concrete with factors affecting it. Popovics (1990) augmented Abram's model, a widely accepted equation variables such as slump; he used least squares regression to determine equation coefficients. This approach improved strength prediction and provided insights into concrete compositions.

Apart from its speed, statistical modeling has two advantages over other techniques: it is mathematically rigorous and it can be used to define confidence intervals for the predictions. These advantages are particularly apparent when comparing statistical modeling with artificial intelligence techniques. Statistical analysis can also provide insight into the key factors influencing 28-day compressive strength through correlation analysis. For these reasons, statistical analysis was chosen as the technique for strength prediction in this study.

2.6 Compressive Strength Test

Compressive strength or compression strength is the capacity of a material or structure to withstand loads tending to reduce size, as opposed to tensile strength, which withstands loads tending to elongate.

2.6.1 Procedures

The concrete is poured in the mould in three layers and tempered properly (ten blows per layer) so as not to have any voids, this is then allowed to harden. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of these specimens should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole area of specimen.

These specimens are tested by compression testing machine at 7, 21 and 28 curing days. Load should be applied gradually on the test specimen until it fails. Load at the failure divided by area of specimen gives the compressive strength of the concrete.

3.0 Results Analysis and Discussion

Table 1.Compressive Strength of Concrete Cubes with different mix ratios.

Sample	Weight (KG)	Density (KG/m^3)	Age of test (Days)	Peak Load (kN)	Sample Stress (N/mm^2)
1:2:4	8.031	2380	7	297	13.2
1:2:4	7.053	2386	14	321	14.27
1:2:4	8.315	2464	21	338.25	15.03
1:2:4	7.751	2297	28	431.25	19.17
1:3:6	7.752	2297	7	243	10.8
1:3:6	7.768	2302	14	276	12.27
1:3:6	7.715	2286	21	271.5	12.07
1:3:6	8.012	2374	28	364.5	16.2

Table 2.Mean Compressive Strength of Concrete Cubes.

Sample description	7 days sample stress	14 days sample stress	21 days sample stress	28days sample stress
1:2:4	13.2	14.27	15.03	19.17
1:3:6	10.8	12.27	12.07	16.20

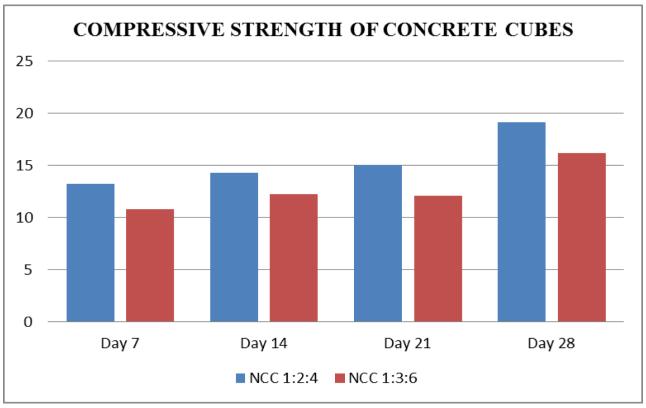

Figure 1. Compressive strength of concrete cubes with varying mix ratios.

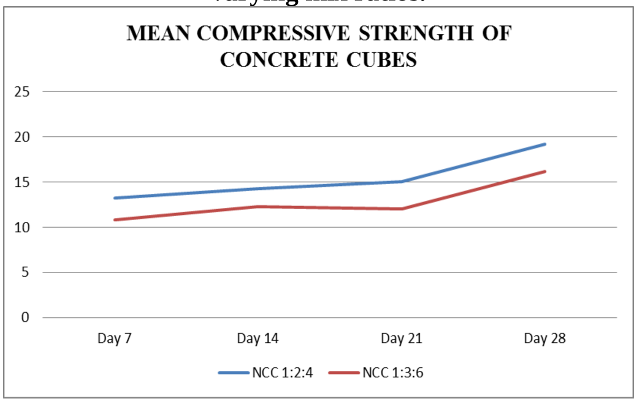

Figure 2. Mean compressive strength of concrete cubes with varying mix ratios.

b = nΣXY – (ΣX)(ΣY) / [nΣX^2 – (ΣX)^2]

Y average = ΣY/n

X average = ΣX/n

Numerator = 2532

Denominator = 8820

b =0.2667

Y avr. = 15.42
X avr. = 17.5

The regression equation therefore is given by the equation below:

a = Y avr – b(Xavr.)
b = 10.753275
Therefore, Y = 10.753275 + 0.26667X

Table 3. Modeling the results obtained using regression analysis for mix ratio 1:2:4.

Serial Number	X	Y	XY	X^2
1	7	13.6	95.2	49
2	7	12.9	90.3	49
3	7	13.1	91.7	49
4	14	14.4	201.6	196
5	14	13.9	194.6	196
6	14	14.5	203	196
7	21	15.5	325.5	441
8	21	14.7	308.7	441
9	21	14.9	312.9	441
10	28	18.9	529.2	784
11	28	19.2	537.6	784
12	28	19.4	543.2	784
Σ	210	185	3433.5	4410

Table 4. Modeling the results obtained using regression analysis for mix ratio 1:3:6.

Serial Number	X	Y	XY	X^2
1	7	10.6	74.2	49
2	7	11.2	78.4	49
3	7	10.7	74.9	49
4	14	12.6	176.4	196
5	14	11.9	166.6	196
6	14	12.3	172.2	196
7	21	12.7	266.7	441
8	21	12.5	262.5	441
9	21	11	231	441
10	28	15.8	442.4	784
11	28	16.5	462	784
12	28	16.3	456.4	784
Σ	210	154.1	2863.7	4410

b = nΣXY – (ΣX)(ΣY) / [nΣX^2 – (ΣX)^2]
Y average = ΣY/n
X average = ΣX/n
Numerator = 2003.4
Denominator = 8820
b =0.22714
Y avr. = 12.84
X avr. = 17.5

The regression equation therefore is given by the equation below:

a = Y avr – b(Xavr.)
b = 8.86505
Therefore, Y = 8.86505 + 0.22714X

3.1 Discussions

I. Table 1 & 2 show both the mean and compressive strength of concrete cubes with different mix ratio (1:2:4 and 1:3:6) at various ages. The compressive strengths were carried out in order to determine the concrete ability to resist loads which tends to compress it. The compressive strength is measured by crushing cylindrical concrete specimens in compression testing machine. The compressive resistance of concrete is calculated by the filaure load divided with the cross sectional area resisting the load.

II. Table 3 & 4 shows the calculation gotten from the data using excel spreadsheet. Rapid determination or prediction of concrete strength could be attained by suitable mathematical model capable of predicting strength of concrete at different ages. The final form of the regression proposed in this study was:

Y = a + bX

Where $b = n\Sigma XY – (\Sigma X)(\Sigma Y) \div [n\Sigma X^2 – (\Sigma X)^2]$

Where $a = \overline{Y} = b\overline{X}$

$\overline{Y} = \Sigma Y/n$

$\overline{X} = \Sigma X/n$

Where n = number of observations
X = age of concrete
Y = compressive strength of concrete

The variables used in the mathematical model of this study are: water, aggregate (fine and coarse) and cement with varying mix ration (1:2:4 and 1:3:6). The basic concept of this model is that us produces a reliable relationship between the compressive strength of concrete and curing age.

4.0 Conclusion and Recommendation

4.1 Conclusion

Earlier and accurate estimation of strength are valuable to the construction industry. The presence of this model would possibly obtained the hard balance and quality between controlling the quality (quality control process) and economics (saving time and expenses) i.e. this could be used in construction to make the necessary on mix proportion used, avoid situation where concrete does not reach require design strength or by avoiding concrete but is unnecessarily strong.

This methodology allows a fast and accurate prediction value for compressive strength on site. Common method for estimation of in place requires extensive used of curing mortar cubes atr constant temperature or the use of database containing large number of compressive strength values made at many ages and cured at different temperatures. The databases have to be fed with statistical relevant number of data before a reliable estimation of ther strength cvan be made. Furthermore, all of the method requires many hours of Lab and field time for testing, collecting and analyzing.

Furthermore, the existing variable in the model yielded good reasonable results. Also, it is not preferred to load the prediction model with number of variables, because it is preferred to use a model with lesser number of variables with most possible accuracy to assure the rapid and easy use of the model. From the research work done, it is observed that concrete strength prediction model is of invaluable asset to construction firm due to the facts that it will ensure safety, reduce construction cost, will save time, monitor strength development and construction quality and durability.

Moreover, prediction of concrete strength is significant from both economics and technical point of view. For instance, when considering the actual strength value at which the structure is being subjected to full load, material safe could be achieved as considered by BS in the track of minimizing environmental pollution. Therefore, it is recommended that more of concrete strength prediction model should be adopted in concrete construction works.

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