Statistical Prediction and Analysis on Parameters of Vibrating Sinking Pipe Gravel Pile Machines

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Abstract. With the rapid development of highway engineering construction in our country, Vibrating Sinking Pipe gravel pile machines have been widely used in soft foundation treatment. The main parameters of the Vibrating Sinking Pipe gravel pile machine are composed of current value, drilling depth and drilling verticality. In this paper, through the analysis of the actual parameter data collected from the intelligent monitoring system of Vibrating Sinking Pipe gravel pile machines in Sichuan Yangtze River Industrial Park, the multiple linear regression prediction model is established by using the regression prediction method; and according to the comparison between the real data and the prediction data, the determination coefficient ranges from 0.83 to 0.95.

Keywords: Vibration Sinking Gravel Piles, Multiple Linear Regression Prediction Models, Coefficient of Determination

1. Introduction
In recent years, China's infrastructure has been developing rapidly, and the total mileage of the highway is increasing year by year. Due to its short period of construction and high efficiency in the treatment of deep soft foundation, the Vibrating Sinking Pipe gravel pile machine has been widely promoted for its significant improvement of bearing capacity of sandy soil, cohesive soil and other types of poor soil foundation [1, 2]. The Yangtze River Industrial Park project in Sichuan mainly includes the Yangtze River South Road, Songyuan Avenue, expressway, the first phase of the secondary road. Its total mileage is 30km. The deep soft foundation treatment (treatment depth ≥ 4m) adopts a vibration immersed tube gravel pile, and the total design length is about 64km. The effective prediction of the main parameters of the Vibrating Sinking Pipe gravel pile machine in the current construction environment can greatly improve the engineering quality and construction efficiency.

Regression prediction technology is a method of forecasting by analyzing the causality and influence degree among things [3-7]. Regression prediction technology is a widely used basic forecasting method. It is found on the analysis of causal models and the influence of external elements on the predicted objects. Therefore, it is applied to the medium and short-term prediction [8-10]. The form of mathematical relationships among of certain variables can be found in regression such as the variable relationship between the regression equations and the parameters of estimation and statistical
test. According to analyze the strength of the relationship and the influence degree between the
influencing elements and the predicted objects, the main elements and the secondary elements can be
found. Finally, based on the results of the regression analysis, the relationship among the variables can
be established. The results of the regression equation and independent variables are applied to predict
the next values of dependent variables. And the fiducial interval and reliability of prediction results are
studied and discussed. Base on the multiple kinds of forms of the functions between the dependent
variables and independent variables, there are linear regression analysis (which is a linear equation)
and nonlinear regression analysis (which is a nonlinear equation).

2. Main Results
When the switch of the motor is turned on, the current is connected. The stranded coil is started by the
motor to pull the wire rope, and the drill pipe of the pile machine can be run. With the increase of drill
pipe depth and foundation bearing capacity, the drop height difference of drill pipe decreases. At the
same time, due to the geographical environment of the pile machine and the huge vibration of the drill
pipe, the verticality of the pile machine and drill pipe changes. Therefore, the drilling depth and the
verticality of the drill pipe is directly determined by the real-time current of the vibrating sinking pipe
gravel pile machine. To find a linear regression prediction model with motor current as the medium
planning objective (dependent variable) and depth and verticality as independent variables become the
key to improve engineering quality and construction efficiency.

2.1 Multiple Linear Regression Model
The ideal of setting up a prediction model through the correlative analysis of one dependent variable
and two or more independent variables is said a multiple regression analysis. Particularly, if there
exists a linear relationship between the independent variable and the dependent variable, it is called a
multiple linear regression analysis.

Let $y$ be the motor current value, $x_1$ be the drill pipe depth difference, and $x_2$ be the verticality
of the drill pipe. The multiple linear regression equation is

$$y = w_1 x_1 + w_2 x_2 + b$$

That is

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} x_{11} & x_{12} & 1 \\ x_{21} & x_{22} & 1 \\ \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & 1 \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ 1 \end{pmatrix}$$

where $w_1, w_2$ are the regression coefficients and $b$ is an offset.

Let $X$, $\bar{X}$ be the training sample and test sample as follows

$$X = \begin{pmatrix} x_{11} & x_{12} & 1 \\ x_{21} & x_{22} & 1 \\ \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & 1 \end{pmatrix}$$

$$\bar{X} = \begin{pmatrix} x_{n+11} & x_{n+12} & 1 \\ x_{n+21} & x_{n+22} & 1 \\ \vdots & \vdots & \vdots \\ x_{n+m1} & x_{n+m2} & 1 \end{pmatrix}$$

where $x_{11}, x_{12}$ are the current depth difference and verticality of the drill pipe at time $t_i$ respectively. Let $Y = (y_1, y_2, \ldots, y_n)^T, \bar{Y} = (y_{n+1}, y_{n+2}, \ldots, y_{n+m})^T$ be the current value vector at time $t_i$. Then the training equations of the multiple linear regression equation from $t_1$ to $t_n$ follow as
and the test equations of the multiple linear regression equation from \( t_{n+1} \) to \( t_{n+m} \) follow as

\[
\begin{pmatrix}
\hat{y}_{n+1} \\
\hat{y}_{n+2} \\
\vdots \\
\hat{y}_{n+m}
\end{pmatrix} = 
\begin{pmatrix}
x_{n+1} & x_{n+12} & 1 \\
\vdots & \vdots & \vdots \\
x_{n+m} & x_{n+m2} & 1
\end{pmatrix}
\begin{pmatrix}
w_1 \\
w_2 \\
1
\end{pmatrix}
\]

2.2 Coefficient of Determination \( R^2 \) and Double population T test

The coefficient of determination is also said to be the goodness of fit, which is the square of the correlative coefficient. This means that the change in the dependent variable can be said by the change in the independent variable. The degree of correlation is determined by the degree of determination coefficient. Generally, the better the coefficient of determination is, the higher the degree of interpretation of independent variables to dependent variables and the rate of change of independent variables in the total change will be. The observable objects will be closed to the regression line. Therefore, the coefficient of determination denotes the numerical characteristics of the connection between a random variable and multiple random variables. It is applied to explain the statistical indicators of the reliability of changing the dependent variable in the regression model, which is defined as

\[
R^2 = \frac{SSR}{SST} = \frac{\sum_{i=n+1}^{n+m} (\hat{y}_i - \bar{y})^2}{\sum_{i=n+1}^{n+m} (y_i - \bar{y})^2}
\]

where SSR is the sum of squares of the total deviation (the total sum of squares), SST is the sum of squares of the interpreted deviation (the sum of squares of regression) and

\[
\bar{y} = \left( \sum_{i=n+1}^{n+m} y_i \right) / m
\]

The job of the two-population T-test is to test whether there is a major difference between the mean of the two samples and the population they indicate. The two-population T-test can be viewed as two cases. One case is the independent sample T-test (there exist no relationship between every experimental treatment set, that is, the independent sample), which is applied to test the difference of the data obtained by the two groups of independent samples. The other is T-test of the associated samples, which is applied to test the difference of the data obtained by two matched groups of subjects or the same group of subjects under different conditions. The samples formed by two cases are the correlative samples. In this paper, we take T-test of the independent sample.

The independent sample T-test statistic is defined as

\[
T = \frac{\bar{y} - \bar{y}}{\sqrt{\frac{(n-1)S^2_1 + (m-1)S^2_x}{m+n-2} \left( \frac{1}{n} + \frac{1}{m} \right)}}
\]

where \( S^2_1 \) is the training sample variance and \( S^2_x \) the test sample variance.

3. Experimental Data
According to the actual parameter data collected in the intelligent monitoring system of the gravel pile machine, the regression equation is introduced. The data in the table 1 are from the intelligent monitoring system of the gravel pile machine in Sichuan Yangtze River Industrial Park in May 2020.

**Table 1.** The data of the gravel pile machine

| t  | y | x₁ | x₂ | t  | y | x₁ | x₂ |
|----|---|----|----|----|---|----|----|
| 1  | 130 | 8  | 0.9 | 7 | 120 | 7.9 | 0.6 |
| 2  | 125 | 8.1 | 0.8 | 8 | 125 | 7.9 | 0.7 |
| 3  | 120 | 8.1 | 0.7 | 9 | 125 | 7.9 | 0.7 |
| 4  | 125 | 7.9 | 0.6 | 10 | 120 | 8   | 0.6 |
| 5  | 130 | 8  | 0.5 | 11 | 125 | 7.8 | 0.5 |
| 6  | 125 | 8.1 | 0.4 | 12| 120 | 7.9 | 0.4 |

where \( t \) is the time of the finishing pile, \( y \) is the motor current value, \( x₁ \) is the depth difference of the drill pipe and \( x₂ \) is the verticality of the drill pipe.

Case 1: If \( n = 6, m = 6 \), then \( R^2 = 0.87 \).
Case 2: If \( n = 9, m = 3 \), then \( R^2 = 0.92 \).
Case 3: If \( n = 10, m = 2 \), then \( R^2 = 0.95 \).

4. Conclusion

Vibrated tube crushed stone pile has been widely used because of its short time limit, high efficiency and significant improvement in the bearing capacity of bad soils such as sandy soil and cohesive soil in deep soft foundation treatment. In this paper, according to the data of the intelligent monitoring system of the vibration immersed tube gravel pile machine in Sichuan Yangtze River Industrial Park, we give the multiple linear regression model of the motor current, drill pipe depth and drill pipe verticality of gravel pile. Based on the model, we give the coefficient of determination between the predicted value and the actual value, which is between 0.83 and 0.95.

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