Material quantity estimation modelling of bridge sub-structure using regression analysis

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Abstract. In construction field, a time completion and an adherence to budget are two factors that mainly influence the successful of the projects. The adherence to the budget can be achieved when the estimated budget is closed to the actual cost. For the owners, cost estimation is necessary as a guidance in determining the amount of investment. Therefore, it is very important to know the estimation of the project cost by using the limited data before the detailed plans and specifications of the project are identified. However, in the case of bridge substructure preliminary cost estimation, there is a lack information about material quantity estimation models due to the difficulties of soil characteristic and hydrological conditions. Hence, this research aims to develop the estimation of material quantity models of the abutment and caisson of bridge, with the Presetressed Concrete I-Girder (PCI Girder) superstructure located in Sleman district, Yogyakarta province, Indonesia. The database used for developing model was obtained by conducting sub-structure structural analysis of 15 abutments and 45 caissons. The bridges have a various span length, abutment height, and caisson depth. Material quantity estimation models were analysed by the multiple regression analysis methods. The span length and the abutment height are determined as independent variables to predict the concrete volume, the reinforcing steel weight, the caisson concrete volume, the cyclops concrete volume and the caisson reinforcing steel weight. This research proposed 11 equation models to estimate the concrete volume and reinforcing steel weight of abutment and caisson.

1 Introduction

In construction field, a time completion and an adherence to budget are two factors that mainly influence the successful of the projects (Fragkakis et.al, 2015). The adherence to the budget can be achieved when the estimated budget is closed to the actual cost. For the owners, cost estimation is necessary as a guidance in determining the amount of investment. Therefore, it is very important to know the estimation of the project cost by using the limited data before the detailed plans and specifications of the project are identified.

Several studies on the cost estimation at an early stage of the projects have been conducted. Initial cost estimation of bridge construction was developed by Muis (1995) for reinforced concrete, truss and composite bridge structure. The model was developed by applying several regression analysis. A study to develop a construction estimation cost model also performed by Lowe, et al. (2006) by developing a cost model estimation of the

building construction by using regression analysis. Fragkakis, et al. (2010) conducted research on a cost estimate method for bridge superstructures using regression analysis and bootstrap. This study aims to develop the cost estimation model of the bridge superstructure of pre-stressed beams, box girders cast in place, and the balance cantilever box girder. Sulistyani (2014) conducted research on the model estimation of the volume and cost of patching on the pavement of provincial roads in Yogyakarta, Indonesia. Fragkakis, et al. (2015) conducted research on the preliminary cost estimation model for culvert. The study aims to develop the cost estimation model using the previous project information.

However, in the case of bridge substructure preliminary cost estimation, there is a lack information about material quantity estimation models due to the difficulties of soil characteristic and hydrological conditions, previous studies only focus to estimate the superstructure cost (Fragkakis et.al, 2011).

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Hence, this research aims to develop the estimation of material quantity models of the abutment and caisson of bridge, with the Presetressed Concrete I-Girder (PCI Girder) superstructure located in Sleman district, Yogyakarta province, Indonesia. The model was figured out by applying the regression analysis.

The regression analysis is one of the most widely used methods for parametric cost estimation at the early project stages. Traditionally, cost estimation is modelled by correlating the previous project data using regression analysis (Fragkakis et.al, 2010). However, the previous project data in Indonesia cannot be used for developing model because the newest version of Indonesian bridge loading standart (SNI 1725: 2016) was enacted on June 2, 2016 in Indonesia. Consequently, in this research, the bridge loading parameter in the design was be assigned based on this code.

2 Research Method

This research was conducted by dividing the procedure into two steps. First, the abutment and caisson structural design was conducted by considering various span length, abutment height and the caisson depth. Afterwards, regarding to the design results, the material quantity estimation models were developed by applying the multiple regression analysis.

The superstructure design was not conducted specifically. However, it was defined based on the product design spesification of Prefabricated Presetressed Concrete I-Girder (PCI Girder) that was produced by Wika Beton, one of Indonesian State-owned Enterprise. Referring to Wika Beton PCI Girder catalogue, the span lenght is restricted from 10 m up to 50 m. The superstructure dimension of the bridge was defined for A-class bridge category in accordance with Indonesian Department of Highway. Related to the category, the bridge has superstructure width of 9 m. The superstructure cross section can be seen in Figure 1.

Fig.1. Bridge cross section

The bridge is located in area that is categorized in seismic zones 3 referred to Indonesian Earthquake Design Bridge Code SNI 2833-2008. The concrete compressive strength of the abutment and caisson was assumed of 20 MPa. The yield strength of reinforced steel was assumed of 390 MPa. As previously describe, the bridge loading parameter used in the design was determined based on SNI 1725:2016 code. The typical form of bridge sub-structure, as presented in Figure 2

Fig.2. Typical form of abutment and caisson

2.1. Soil characteristic

The soil characteristic for structural analysis was determined as the 10 percentile from the 15 bridges soil investigation results located in Yogyakarta. The soil characteristic of 15 bridges can be seen in Table 1.

Table 1. Soil characteristic

Bridge Name	Subgrade under pile cap		Subgrade under the caisson	
	Density (kN/m ³)	Internal Friction (°)	Density (kN/m ³)	Internal Friction (°)
Gamping Bridge	19	37	19	37
Grembyangan Bridge	19	36	19	36
Wonosobo Bridge	18,3	35	18,3	35
Rejodani Bridge	18,3	35	18,3	35
Cebongan Bridge	19	37	19	37
Temanggal Bridge	18,3	35	18,3	35
Pereng Bridge	17,3	34	17,3	34
Kembang Putih Bridge	18,3	35	18,3	35
Merah Bridge	18,3	35	18,3	35
Pojok Bridge	18,3	36	18,3	36
Tapan Bridge	18,3	35	18,3	35
Kragilan Bridge	18,3	35	18,3	35
Sambiroto Bridge	18,3	35	18,3	35
Balerejo Bridge	18	35	18	35
Bedoyo Bridge	19,2	37	19,2	37

Based on the 10 percentile calculation result of soil charactristic data, the density and the internal friction angle of subgrade at bottom of the caisson are 18 kN/m³

and 35° , respectively. The density and the internal friction angle of subgrade at the bottom of the pile cap are 18 kN/m^3 and 35° , respectively.

It was assumed that the required cone penetration resistance was achieved in 4 m, 5 m and 6 m under the bottom surface of pile cap, as illustrated in Figure 2. As a result, there were three types of the caisson height, those were 4 m, 5 m and 6 m.

2.2 Database development

The database was developed by designing the abutment and the caisson structure with various of bridges span length, the abutment height and the caisson depth. In the design for developing database, the bridges have five span length variations, *i.e.*, 20m, 25m, 30m, 35m, and 40 m. The abutment height variations are 4m, 6m, and 8m. The caisson depth variations are 4m, 5m, and 6m. Hence, the number of data base obtained from the design results of abutment and caisson structure are 15 and 45, respectively. For each data, the volume of concrete and the weight of reinforcing steel are then applied to make the material estimation quantity model.

2.3. Material quantity estimation model

Material quantity estimation model was developed by taking into account the variables that considerable influence the dimensions of the structure and reinforcing requirements. Consequently, the span length L and the abutment height H were defined as independent variables, as illustrated in Figure 3. The volume of concrete at the abutment V_c , reinforcing steel weight of the abutment V_s , concrete volume of caisson V_{cs} , volume of cyclops concrete V_{cc} , and reinforcing steel weight of caisson V_{ss} were defined as dependent variables.

Fig.3. Longitudinal section of the bridge

3 Results And Discussion

3.1. Design result

In this paper, the design result of the abutment and caisson structure are represented by correlation chart between independent variables and dependent variables. The influence of bridge span L towards the concrete volume

V_c and the reinforcing steel weight V_s of the abutment can be seen in Figure 3 and Figure 4, respectively. Both figures typically showed that the greater bridge span and abutment height, the more material quantity is required.

In the case of 4 m caisson depth, the effect of bridge span L towards the concrete volume of caisson V_{cs} , the cyclops concrete volume V_{cc} and the caisson reinforcing steel weight V_{ss} can be seen in Figure 5, Figure 6 and Figure 7, respectively. In the case of 5 m caisson depth, the effect of bridge span L towards the concrete volume of caisson V_{cs} , the cyclops concrete volume V_{cc} and the caisson reinforcing steel weight V_{ss} can be seen in Figure 8, Figure 9 and Figure 10, respectively. In the case of 6 m caisson depth, the effect of bridge span L towards the concrete volume of caisson V_{cs} , the cyclops concrete volume V_{cc} and the caisson reinforcing steel weight V_{ss} can be seen in Figure 11, Figure 12 and Figure 13, respectively. Like the material quantity required on the abutment, the greater bridge span and abutment height, the more material volume is required.

Fig.3. Correlation between bridge span and concrete volume of the abutment

Fig.4. Correlation between bridge span and reinforcing steel weight of the abutment

Fig.5. Correlation between concrete volume and span of the 4 m caisson

Fig.8. Correlation between concrete volume and span of the 5 m caisson

Fig.6. Correlation between cyclops concrete volume and span of the 4 m caisson

Fig.9. Correlation chart between cyclops concrete volume and span of the 5 m caisson

Fig.7. Correlation between reinforcing steel weight and span of the 4 m caisson

Fig.10. Correlation chart between reinforcing steel weight and span of the 5 m caisson

Fig.11. Correlation between concrete volume and span of the 6 m caisson

Fig.12. Correlation between cyclops concrete volume and span of the 6 m caisson

Fig.13. Relation between reinforcing steel weight and span of the 6 m caisson

3.2 Statistical analysis

3.2.1 Multiple linear regression analysis

In general, multiple regression analysis was applied to obtain the relation of material quantity to the bridge span, the height of abutment and the height of caisson base on material quantity obtained from design results. The relation of concrete volume V_c and reinforcing steel weight V_s to the bridge span L and the abutment height H can be seen in Equation 1 and 2, respectively.

$$V_c = -354,365 + 4,6L + 91,838H \quad (1)$$

$$V_s = -22988,353 + 290,209L + 7311,548H \quad (2)$$

For the 4 m height caisson, the relation of concrete volume of the caisson V_{cc} , cyclops concrete volume V_{cc} and reinforcing steel weight V_{ss} to the bridge span L and the abutment height H can be seen in Equation 3, 4 and 5, respectively.

$$V_{cs} = -91,23 + 1,693L + 36,159H \quad (3)$$

$$V_{cc} = -113,824 + 1,877L + 26,256H \quad (4)$$

$$V_{ss} = -2438,132 + 104,176L + 1576,658H \quad (5)$$

For the 5 m height caisson, the relation of concrete volume of the caisson V_{cc} , cyclops concrete volume V_{cc} and reinforcing steel weight V_{ss} to the bridge span L and the abutment height H can be seen in Equation 6, 7 and 8, respectively.

$$V_{cs} = -81,687 + 1,57L + 38,154H \quad (6)$$

$$V_{cc} = -138,972 + 2,276L + 36,113H \quad (7)$$

$$V_{ss} = -1668,902 + 75,651L + 1598,17H \quad (8)$$

For the 6 m height caisson, the relation of concrete volume of the caisson V_{cc} , cyclops concrete volume V_{cc} and reinforcing steel weight V_{ss} to the bridge span L and the abutment height H can be seen in Equation 9, 10 and 11, respectively.

$$V_{cs} = -104,243 + 1,9456L + 43,449H \quad (9)$$

$$V_{cc} = -208,735 + 3,755L + 48,551H \quad (10)$$

$$V_{ss} = -2281,826 + -51,57 + 1527,253H \quad (11)$$

3.2.2 Normality test

Normality test aims to determine whether or not the residuals variable of regression models have normal distribution. The t test and F test assumes that the residuals have a normal distribution. If this assumption is violated, the statistical test becomes invalid for a small number of samples. In this research, normality test data is conducted by using the Kolmogorov-Smirnov test. In this test, the data is normally distributed if the asymptotic significance value is greater than 0.05. Normality test results as shown in Table 2. The results depict that the residuals data has normal distribution.

Table 2. Normality test results

Structure	Dependent Variable	Asymptotic significance	Distribution
Abutment	V_c	0.20	Normal
	V_s	0.20	Normal
4m caisson	V_{cs}	0.074	Normal
	V_{cc}	0.20	Normal
	V_{ss}	0.20	Normal
5 m caisson	V_{cs}	0.062	Normal
	V_{cc}	0.20	Normal
	V_{ss}	0.20	Normal
6 m caisson	V_{cs}	0.20	Normal
	V_{cc}	0.20	Normal
	V_{ss}	0.149	Normal

3.2.3 Multicollinearity test

Multicollinearity test aims to determine whether the regression model found a correlation between independent variables. If independent variables in the regression models are strongly correlated each other, dependent variable resulted from the regression model is not reliable. The presence of multicollinearity can be determined by calculating the value of tolerance and the variance inflation factor (VIF). If the tolerance values are greater than 0.1 and VIF are less than 10, it means that there are no multicollinearity problem. The multicollinearity test results between independent variables described in Equation 1 up to Equation 11 shows that both of tolerance values and VIF value are 1. It can be determined that there are no multicollinearity problems in the regression models.

3.2.4 Correlation analysis

Correlation analysis was conducted to observe the correlation between dependent and independent variables. In this research, the multiple correlation analysis was applied. The multiple correlation analysis aims to determine the correlation direction and strength of two or more independent variables simultaneously towards a dependent variable. The result of multiple correlation analysis shows that both independent variables, that consist of the bridge span L and abutment height H expressed in Equation 1 to Equation 11, strongly influence the dependent variables with a correlation coefficient exceed 90%, as shown in **Table 3**.

Table 3. Correlation test results

Structure	Independent Variable	Correlation Coefficient
Abutment	V_c	0.986
	V_s	0.985
4 m Caisson	V_{cs}	0.980
	V_{cc}	0.967
	V_{ss}	0.961
5 m Caisson	V_{cs}	0.980
	V_{cc}	0.967
	V_{ss}	0.923
6 m Caisson	V_{cs}	0.982
	V_{cc}	0.967
	V_{ss}	0.970

3.2.5 Goodness of fit of a linear regression

The coefficient of determination, denoted R², was calculated to measured how the linear regression model fit the design results of material quantity, called as the goodness of fit.

The R² has the interval between 0 and 1. The larger value of R² indicates the better results of the regression model to predict the dependent variable. The coefficient of determination R² test results can be seen in **Table 4**. It can be seen that the R² values for all regression equations exceed 0.9. It indicates that the proposed model can satisfactory in estimating the material quantity of bridge sub structure.

Table 4. The coefficient of determination test R²

Structure	Dependent Variable	R ²	Standart error of estimate
Abutment	V_c	0.972	20.09
	V_s	0.970	2398.46
4 m caisson	V_{cs}	0.961	13.62
	V_{cc}	0.965	13.55
	V_{ss}	0.921	876.68
5m caisson	V_{cs}	0.960	14.43
	V_{cc}	0.935	17.99
	V_{ss}	0.968	539.9
6m caisson	V_{cs}	0.964	15.57
	V_{cc}	0.935	24.67
	V_{ss}	0.941	1064.109

4 Conclusion

This research proposed 11 equation models to estimate the concrete volume and reinforcing steel weight of abutment and caisson. Based on the results of statistical analysis, it can be seen that the coefficient of determination R² for all proposed model exceed 0.9. It indicates that the proposed

model can satisfactory estimate the material quantity of bridge sub structure. Based on multiple correlation test, it can be concluded that the concrete volume and reinforcing steel weight of abutment and caisson are strongly influenced by the span length and height of the abutment.

References

1. The National Standarization Agency of Indonesia, Standard of earthquake resistant design for bridges (SNI 2833:2008), Jakarta: BSN. (2008) [in Indonesian]
2. The National Standarization Agency of Indonesia, Bridges Loading Standard (SNI 1725:2016), Jakarta: BSN. (2016) [in Indonesian]
3. Fragkakis, N., Pantouvakis, J.P., Lambropoulos, S., (2010), A cost estimate method for bridge superstructures using regression analysis and bootstrap: organization, technology and management in construction, *An International Journal*, 2(2): 182-191
4. Fragkakis, N., Marinelli, M., Lambropoulos, S., Preliminary Cost Estimation Model For Culvert, *Procedia Engineering*, **123**, 153 – 161 (2015)
5. Fragkakis, N., Lambropoulos, S., Tsiambaos, G., Parametric Model for Conceptual Cost Estimation of Concrete Bridge Foundations, *Journal of infrastructure systems*, **17**, 66-74 (2011)
6. Hollar, D., Rasdorf, W., Liu, Hummer, J., Arocho, I., Hsiang, S., Preliminary Engineering Cost Estimation Model for Bridge Projects, *Journal of construction engineering and management*, **139**, 1259-1267 (2013)
7. Lowe, D. J., Emsley, M. W., Harding, A., Predicting Construction Cost Using Multiple Regression Techniques. New York: ASCE, *Journal Of Construction Engineering And Management*.
8. Muis, A. R., Preliminary Cost Estimation of Bridge Construction. Thesis. Bandung: Bandung Institute Of Technology (1995) [in Indonesian]
9. Sulistyani, H., Volume and Cost Estimation Model of Patching Work (Case Study of National Roads under Management of Local Service Unit in Yogyakarta Special District). (2014) [in Indonesian]
10. WIKABeton, Standard Product Drawing. Bekasi: PT Wijaya Karya Beton. (2012) [in Indonesian]