Jurnal
Teknologi

Full Paper

MULTIPLE LINEAR REGRESSION MODELLING FOR THE COMPACTION CHARACTERISTICS OF SEDIMENTARY SOIL MIXED BENTONITE AS COMPACTED LINER

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Article history
Received
4 April 2023
Received in revised form
12 June 2023
Accepted
14 July 2023
Published Online
20 October 2023

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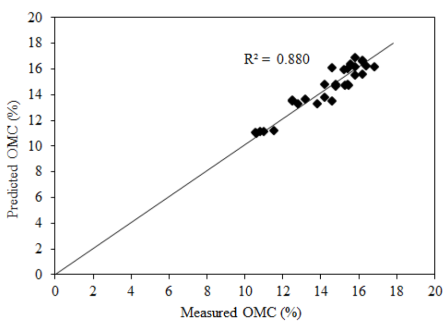
Graphical abstract



Abstract

This paper attempts to develop a prediction model for compaction characteristics such as maximum dry density (MDD) and optimum moisture content (OMC) of sedimentary residual soil mixed with bentonite as compacted liner. This prediction model was based on the laboratories testing data such as compaction testing and Atterberg limit testing of residual soil mixed with bentonite. Meanwhile, compaction testing was conducted at the different compaction energies. The Multiple Linear Regression (MLR) analysis method was selected to develop a model in determining the maximum dry density (MDD) and optimum moisture content (OMC). The predicted compaction model developed in this study was validated in accordance with the statistical validation steps and conditions. It was found from the modelling analysis, the significant relationship between the compaction energies (E) and OMC for MDD model. Meanwhile, it shows the significant relationship between liquid limit (LL), plastic limit (PL), percentage bentonite (B) and compaction energies (E) for OMC model. The fitted regression model shows the reasonably good regression coefficient for MDD model is (R^2 = 78.5%) and for OMC model is (R^2 = 71.9%). The models were validated by comparing between the predicted model with measured model data from published study data. It was found, the determination coefficient and mean square error (MSE) for validated model between the predicted model and the measured models gave a value of R^2 = 88.7% with MSE = 0.12% for MDD model and R^2 = 88% with MSE = 4.3% for OMC model. In conclusion, the models developed in this study present a good prediction for MDD and OMC.

Keywords: Compaction, sedimentary residual soil, bentonite, soil liner, regression modelling

Abstrak

Kertas kerja ini membentangkan pembentukan model regrasi ramalan untuk pemadatan tanah dalam menentukan ketumpatan kering maksimum (MDD) dan kandungan lembapan optimum (OMC) untuk tanah sisa sedimen bercampur dengan bentonit sebagai pelapik tanah padat. Pembentukan model ramalan ini dibentuk daripada data-data ujian makmal seperti ujian pemadatan dan ujian had Atterberg untuk tanah sisa yang dicampur dengan bentonit. Sementara itu, ujian pemadatan dijalankan pada tenaga pemadatan yang berbeza. Kaedah analisis regresi linear berbilang (MLR) telah dipilih untuk membangunkan model dalam menentukan ketumpatan kering maksimum

(MDD) dan kandungan lembapan optimum (OMC). Model pemadatan ramalan yang dibangunkan dalam kajian ini telah disahkan mengikut langkah dan syarat pengesahan statistik. Didapati daripada keputusan analisis pemodelan, terdapat hubungan yang signifikan antara tenaga pemadatan (E) dan OMC untuk model MDD. Manakala didapati terdapat hubungan yang signifikan antara had cecair (LL), had plastik (PL), peratusan bentonit (B) dan tenaga pemadatan (E) bagi model OMC. Model regresi yang sesuai menunjukkan pekali regresi yang cukup baik untuk model MDD ialah R2 = 78.5% dan untuk model OMC ialah R2 = 71.9%. Model-model tersebut telah disahkan dengan membandingkan diantara model ramalan dengan data diukur daripada data kajian yang telah diterbitkan. Didapati daripada analisis ini, pekali penentuan dan ralat min kuasa dua (MSE) bagi model ramalan dan model yang diukur telah memberikan nilai R2 = 88.7% dengan MSE = 0.12% untuk model MDD dan R2 = 88% dengan MSE = 4.3% untuk model OMC. Kesimpulannya, model yang dibangunkan memberikan ramalan yang baik untuk MDD dan OMC.

Kata kunci: Pemadatan, tanah baki sedimen, bentonit, pelapik tanah, regresi model

1.0 INTRODUCTION

Engineering projects that involve earthwork in landfill area often require a good engineered soil liner as a base layer and should meet certain engineering criterion for liner. Proctor (1933) suggested to compact the soil at a desired compaction energy with various water contents in the laboratory to obtain the optimum water content and the maximum dry density from the compaction curve [1]. Thus, to maintain the long-term performance of compacted soil liner in landfill area, these two compaction parameters are widely used in compaction criteria for the design and construction of soil liner [2], [3]. The compacted liners commonly used in landfill area as a soil liner used to prevent the groundwater contamination and this soil liner performance is affected by the soil compaction characteristics due to the soil compaction performances is an important role to the requirement of hydraulic conductivity for soil liner to prevent the leachate [4], [5], [6], [7]. Therefore, the compaction of soil needs to be carried out appropriately to avoid the change of soil structure that may lead to the change in soil permeability and the compaction process needs to be performed layer by layer. Bentonite application is widely used in civil engineering especially for hydraulic flow barrier for compacted soil liner in landfills liners and cover systems. Bentonite is mixed with residual soil if natural clay or clayey soils are not available on site [8], [9].

Due to the limited budget, poor planning conditions or insufficient site investigation data, civil engineers always face difficulty obtaining on-site compaction values for liner design purposes. In fact, compaction testing in the laboratory is not only difficult and time-consuming although results are sometimes imprecise due to sample interference and poor quality of laboratory testing conditions. There are limited attempts have been made previously to develop predicted models for predicting compaction characteristics especially for the compaction parameter of residual soil mixed bentonite were noticed despite of their practical significance [10], [11], [12], [13]. Therefore, the development of predictive models may be useful and form the basis of judgment about the validity of compaction values and important for the construction and the maintenance of the geotechnical structures [14], [15].

This paper present the prediction model for compaction parameters for sedimentary residual soil mixed bentonite by using the multiple linear regression analysis. By using the developed model, the MDD and OMC of sedimentary residual soil mixed can be estimated easily before or without the laboraratory work.

2.0 METHODOLOGY

The yellowish Grade VI sedimentary residual soil sample used in this study was collected from Salak Tinggi, Selangor, Malaysia. Meanwhile, the grey powder of sodium bentonite used in this study was mixed with sedimentary residual soil to produce the mixture of soil-bentonite samples. The soil (S) sample was mixed uniformly with 5%, 10% and 15% bentonite (B) content at dry weight of soil. The mixed soil sample was tested for the physical properties according to BS 1377: Part 2 and for compaction testing [16]. Table 1 shows the physical properties results for sedimentary residual soil mixed with bentonite.

Table 1 Soil properties result from experimental studies

Properties	S	S+5B	S+10B	S+15B
Plastic Limit, *LL* (%)	28.85	33.07	42.82	51.92
Liquid Limit, *PL* (%)	18.07	20.00	23.69	26.85
Plasticity Index, *PI* (%)	10.78	13.07	19.13	25.07
Gravel (%)	0.00	0.00	0.00	0.00
Sand (%)	69.14	63.63	61.42	59.33
Silt (%)	20.92	17.93	15.59	16.11
Clay (%)	9.94	18.44	22.99	24.56

The compaction test was carried out to determine the MDD and OMC for the mixed soil samples at different compaction energy. The compaction testing was conducted as per BS1377: Part 4:1990 for British Standard Light (BSL) and British Standard Heavy (BSH). Meanwhile, other two types of compactions were performed derived from the previous researchers such as Reduced British Standard Light (RBSL) and West African Standard (WAS) [17][18][19]. Table 2 shows the compaction result for MDD and OMC at different energies of compaction. The compaction energy derived from the Equation 1 as shown below:

$$E = \frac{\left[\left(\begin{matrix}Number\ of\\ blows\ per\ layer\end{matrix}\right) \times \left(\begin{matrix}Number\ of\\ layers\end{matrix}\right) \times \left(\begin{matrix}Weight\ of\\ Rammer\end{matrix}\right) \times \left(\begin{matrix}Height\ of\\ drop\end{matrix}\right)\right]}{Volume\ of\ mould} \quad (1)$$

Table 2 Compaction results from experimental study

Sample	Compaction Types	Compaction Energy (*E*) (kNm/m³)	Maximum Dry Density (*MDD*) (Mg/m³)	Optimum Moisture Content (*OMC*) (%)
S	RBSL	336.6	1.82	14.50
	BSL	605.9	1.88	13.50
	WAS	1008.7	1.90	12.50
	BSH	2723.5	2.02	10.00
S + 5B	RBSL	336.6	1.76	16.50
	BSL	605.9	1.86	14.00
	WAS	1008.7	1.91	13.00
	BSH	2723.5	2.00	11.00
S +10B	RBSL	336.6	1.67	18.50
	BSL	605.9	1.78	15.00
	WAS	1008.7	1.85	14.00
	BSH	2723.5	1.93	12.50
S +15B	RBSL	336.6	1.58	19.00
	BSL	605.9	1.74	15.00
	WAS	1008.7	1.78	15.50
	BSH	2723.5	1.97	11.50

The multiple linear regression (MLR) model analysis was carried out on this study to estimate the MDD value and OMC value. A suitable model was accomplished with coefficient of regression, R^2. Meanwhile, the hypothesis testing was carried out to find out whether the observations studied on the sample are within the confidence level. Therefore, the T-Test was performed for the hypothesis testing and the rejection or acceptance of a tested hypothesis was determined at a confidence level of 95% or 0.95. This confidence level produced the significant level of 5% or 0.05 which is given by the symbol of P = 0.05

To develop the multi linear correlation, data set was divided as dependent variables such as MDD and OMC as well as independent variables such as liquid limit (LL), plastic limit (PL), percentage bentonite (B), compaction energy (E) and optimum moisture content (OMC). To develop a MLR model, a complete of 40 primary datasets were used which were obtained from the experimental result and the new 30 datasets for validation were collected from the secondary data such as from journals, technical paper, proceeding, and research report. The relationship between the predicted models versus the measured data was carried out for model validation and the plot shows the scatter point closely between the predicted and measured value [20]. Omar *et al.,* (2018) stated that the model is reliable when it fits to the three requirement such as coefficient of determination (R^2), mean square error (MSE) and T-Test [21].

3.0 RESULTS AND DISCUSSION

Two variable parameters have been used in the MLR for MDD model including optimum moisture content (OMC) and compaction energy (E). The regression model to estimate the MDD as shown in Equation 2.

$$MDD(Mg/m^3) = 1.35 – 0.0117\ OMC + 0.22\ Log\ E \quad (2)$$

Meanwhile four parameters have been used for OMC model including the liquid limit (LL), plastic limit (PL), percentage of bentonite (B) and compaction energy (E). The regression model estimates the OMC as shown in Equation 3.

$$OMC(\%) = 26.55 + 0.104(LL - 0.065PL - 0.47Bt) - 5.41Log\ E \quad (3)$$

The reasonably good regression model obtained for these two models was discussed in detail and the good regression model developed was validated and discussed in accordance with the statistical validity conditions. Tables 3 and 4 show the descriptive statistic result for MDD model and OMC model respectively for a group of 40 data set samples. The descriptives statistics are needed to understand the characteristics of selected samples more easily. The descriptive results show the statistical detail, and it was found that the relationship of each parameter has a standard skewness and a standard kurtosis in the range of -2 and 2. It can be seen, the data is normally scattered in a normal distribution graph with a skewed. George and Mallery (2010) stated that any score for skewness and kurtosis is in the range -2 and 2, it can be accepted as a normal requirement [22].

Table 3 Descriptive statistic result for MDD model

Variable	Mean	Min.	Med	Max	Skewness	Kurtosis
OMC	14.79	10.73	14.42	19.24	0.32	-1.05
Log E	2.94	2.53	2.89	3.44	0.35	-1.17

Table 4 Descriptive statistic result for OMC model

Variable	Mean	Min.	Med	Max	Skewness	Kurtosis
(LL - 0.065PL - 0.47Bt)	39.68	28.86	41.32	51.99	-0.20	-1.38
Log *E*	2.94	2.53	2.89	3.44	0.35	-1.17

Table 5 shows the summarization result from multiple linear regression modelling for MDD model and OMC model. For a normality result, it shows that MDD model and OMC model is at the higher of significance level which is the P-Value > 0.05 from the Anderson Darling test, Ryen Joiner test and Kolmogorov Smirnov test. This indicate that the data set was well modelled by a normal distribution, and it show the residuals data result do not seem to deviate from a random sample from a normal distribution in any systematic manner.

Meanwhile, the regression analysis result in Table 4 shows that the MDD model and OMC model is at significance level with P-Value<0.05 with the coefficient of determination, R-squared (R^2) was giving more than 70% for both models. This indicates that the OMC and compaction energies (E) significantly affected the MDD value. Meanwhile, it was found that the compaction energy (E) and combination of soil properties such as liquid limit (LL), plastic limit (PL) and bentonite (B) content significantly affected the OMC value.

Based on the analysis of variance result for MDD model and OMC model in Table 4, it shows that the regression model developed provides significant information for predicting the MDD and OMC value. This based on the significance level which the P-Value < 0.05. This shows that the parameters for the OMC model and MDD model are reliable. Another criterion to select the best regression model is to consider the MS value criterion for small residual errors. Therefore, the results show that all MS values from the OMC model and MDD model have given the lowest values for the residual error.

Table 5 Summarize multiple linear regression result for MDD model and OMC model

Model	Test	P-Value	R^2 (%)
MDD	**Normality Result:**		
	Anderson Darling	0.455	-
	Ryen-Joiner	> 0.10	-
	Kolmogorov Smirnov	> 0.15	-
	Regression Analysis Result:		
	Constant	0.00	
	OMC	0.012	78.5
	Log *E*	0.00	
	Analysis of Variance:		
	Regression	0.00	-
	Residual Error	-	-
OMC	**Normality Result:**		
	Anderson Darling	0.265	-
	Ryen-Joiner	> 0.10	-
	Kolmogorov Smirnov	> 0.15	-
	Regression Analysis Result:		
	Constant	0.00	
	(LL-0.065PL-0.472Bt)	0.00	71.9
	Log *E*	0.00	
	Analysis of Variance:		
	Regression	0.00	-
	Residual Error	-	-

The model feasibility determination was measured to evaluate the validity of the developed models. The evaluation and comparison models between predicted and measured models were made and the results are shown in Table 5. From the T-Test result, it shows the P-value is 0.225 for MDD model and 0.130 for OMC model which is bigger than α = 0.05. Thus, it indicates that there is no significant difference between the mean for predicted of MDD or OMC as well as MDD or OMC measured. Once the output result fits with the data set, the variance of residual error (MSE) value should be minimum. It can be seen from the result in Table 6, the MSE values involved in the prediction against the measured value for MDD and OMC were 0.12% and 4.3% respectively. It shows the lower MSE value will provide higher accuracy for both prediction models. However, the error involved with OMC model slightly higher compared to MDD model, implying that MDD is more dependent on the OMC. Meanwhile, the good regression coefficients obtained in both models are R^2 = 0.887 for MDD model and R^2 = 0.880 for OMC model. The accuracy of both models was verified by comparing the data distribution between predicted MDD and OMC value with measured values from published works as shown in Figure 1 and Figure 2.

Table 6 Validation for MDD and OMC model based on predicted versus measured

Model	T-Test (P-Value)	MSE	R^2
MDD	0.225	0.0012	0.887
OMC	0.130	0.043	0.880

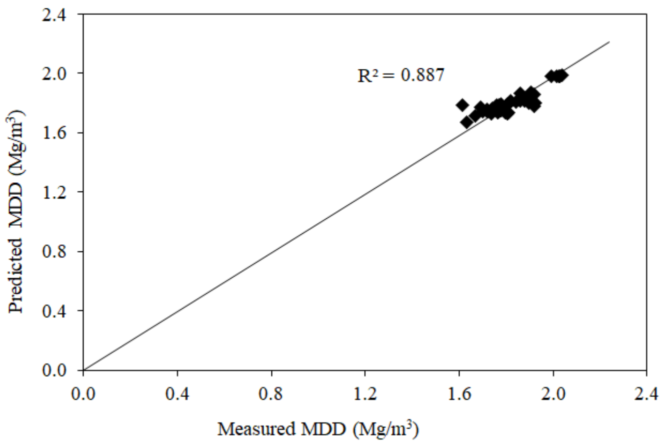


Figure 1 Graph of predicted MDD vs measured MDD

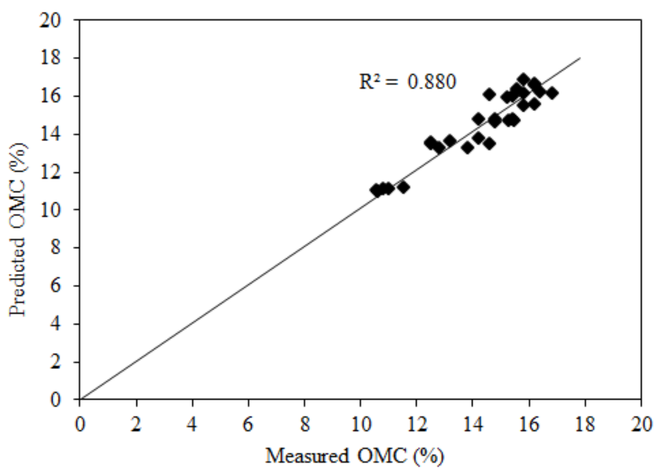


Figure 2 Graph of predicted OMC vs measured OMC

4.0 CONCLUSION

In this study, the prediction compaction model for mixed soil-bentonite such as value for MDD and value for OMC was developed using a MLR method. The predicted models were developed and validated using statistical steps and conditions. The validation of the prediction models was compared with the measured data, the prediction models were found useful in predicting the value for MDD and OMC. It was proved in statistical conditions, the models better in predicting the MDD value and OMC value due to the reasonably good regression coefficient for MDD model and OMC model is R^2 = 78.5% and R^2 = 71.9% respectively. Meanwhile the mean square is 0.12% for MDD model at determination coefficient is R^2 = 88.7% and mean square is 4.3% for OMC model at determination coefficient is R^2 = 88%.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Acknowledgement

The authors fully acknowledge to the Universiti Teknologi Malaysia, Shah Alam for providing Myra Research Grant 600-RMC 5/3/GPM (065/2022) to complete this research study and to the School of Civil Engineering, Universiti Teknologi MARA, Malaysia for providing the facilities such as the geotechnical laboratory and advanced geotechnical laboratory to accomplish this study.

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