

# The Estimation of Compaction Parameter Values Based on Soil Properties Values Stabilized with Portland Cement

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**Abstract.** The strength and durability of pavement construction is highly dependent on the properties and subgrade bearing capacity. This then led to the idea of the selection methods to estimate the density of the soil with the proper implementation of the system, fast and economical. This study aims to estimate the compaction parameter value namely the maximum dry unit weight ( $\gamma_{d \max}$ ) and optimum moisture content ( $w_{opt}$ ) of the soil properties value that stabilized with Portland Cement. Tests conducted in the laboratory of soil mechanics to determine the index properties (fines and liquid limit) and Standard Compaction Test. Soil samples that have Plasticity Index (PI) between 0-15% then mixed with Portland Cement (PC) with variations of 2%, 4%, 6%, 8% and 10%, each 10 samples. The results showed that the maximum dry unit weight ( $\gamma_{d \max}$ ) and  $w_{opt}$  has a significant relationship with percent fines, liquid limit and the percentation of cement. Equation for the estimated maximum dry unit weight ( $\gamma_{d \max}$ ) =  $1.782 - 0.011*LL + 0,000*F + 0.006*PS$  with  $R^2 = 0.915$  and the estimated optimum moisture content ( $w_{opt}$ ) =  $3.441 + 0.594*LL + 0,025*F + 0,024*PS$  with  $R^2 = 0.726$ .

## 1. Introduction

Strength and durability of pavement construction is dependent on the soil properties and subgrade bearing capacity. Compaction is a treat that using to obtain a stable soil bearing capacity [1]. The parameter values obtained from the compaction experiment to obtain the maximum dry unit weight ( $\gamma_{d \max}$ ) and optimum moisture content ( $w_{opt}$ ).

In determining the value of the compaction parameters will need a lot of material, high cost for the testing, the expert operators in laboratory and taking a lot of times in laboratory. On the other side, the testing to determine an index value of subgrade material properties is not difficult, it does not need an expensive equipment and time for testing is also shorter [2]. If the results from the value of index properties can be used to predict the maximum dry unit weight and optimum water content of a subgrade material, obviously will be able to save time, energy and cost for the implementation process.

There was a research on the determination of the maximum dry weight of aggregate for subbase and research on the estimation of parameters compaction of aggregate for subgrade based on the data of index properties [3]. This study aims to estimate the parameters of compacting used for subgrade layer with Plasticity Index (PI) between 0-15%. By using the linear regression equation, the values of laboratory compaction parameter estimated (maximum dry unit weight and optimum water content) subgrade material mixed with Portland Cement based on the data of soil index properties (fines and liquid limit) and the addition of cement content[4].



## 2. Literature Reviews

Compaction is a process to pull out the air in the soil's pores by mechanical method. Mechanical method that used to compact the soil can be used in various ways. In practice usually by grinding, but in laboratory by pounding using a proctor. The physical properties of the soil (index properties) showed the soil properties that indicate the type of soil (classification) and soil conditions and provides a connection to the mechanical properties (engineering properties) such as strength and compression or a tendency to inflate and permeability. The physical properties of the soil (index properties) include moisture content, density, Sieve Analysis, Atterberg Limit Test and others.

Several studies for estimating the value of soil compacting (maximum dry unit weight and optimum water content) has been developed. Research to determine the relation between the parameters of compaction, firstly done by Johnson and Sallberg (1962). Then followed by the study of Al-Khafaji (1993) and formulate the relation between the value of compacting with Atterberg Limits into an equation as follows:

For the soil in Irak,

$$\text{MDD} = 2,44 - 0,22\text{PL} - 0,008\text{LL} \quad (1)$$

$$\text{OMC} = 0,24\text{LL} + 0,63\text{PL} - 3,13 \quad (2)$$

For the soil in America,

$$\text{MDD} = 2,27 - 0,19\text{PL} - 0,003\text{LL} \quad (3)$$

$$\text{OMC} = 0,14\text{LL} + 0,54\text{PL} \quad (4)$$

By the Boltz empiric Equation, et.al (1998), found an equation of linier relation between maximum dry unit weight by using compaction pounding. The result from correlation formulated in a linier equation as follows :

$$\text{MDD} = (2,27 \text{ Log LL} - 0,94) \text{ Log E} - 0,16\text{LL} + 17,02 \quad (5)$$

$$\text{OMC} = (12,39 - 12,21 \text{ Log LL}) \text{ Log E} + 0,67\text{LL} + 9,21 \quad (6)$$

Then Ugbe (2012) suggested an equation to predict the maximum dry unit weight and optimum moisture content by using index properties value (fines percentage, liquid limit and specific gravity) with this equation :

$$\text{MDD} = 15,665\text{SG} + 1,526\text{LL} - 4,313\text{F} + 2011,960 \quad (7)$$

$$R^2 = 0,895$$

$$\text{OMC} = 0,129\text{F} - 0,0196\text{LL} - 1,4233\text{SG} + 11,399 \quad (8)$$

$$R^2 = 0,795$$

## 3. Research Methods

The number of samples examined 50 samples with a range of values Plasticity Index (PI) between 0-15%. Then the sample is mixed with Portland Cement (PC) with a variation of 2%, 4%, 6%, 8% and 10%, 10 samples for each percentage. The general equation used in determining the regression equation is as follows:  $Y = aX + b$

by: Y = maximum dry bulk density ( $\gamma_d$  max)/optimum moisture content ( $W_{opt}$ ); X = index properties (fines/liquid limit) and the percent addition of cement; a = constant variable and b = variable.

If a strong relation is obtained for each variable then continued using two variables and then the three variables. The accuracy of the correlation between variables measured by the coefficient of determination ( $R^2$ ) as listed in Table 1.

**Table 1.** Accuracy Coefficient Of Determination ( $R^2$ )

Values of $R^2$	Accuracy
< 0,25	Not Good
0,25 – 0,55	Relatively Good
0,56 – 0,75	Good
> 0,76	Very Good

Source : Kamarudin (2005)

## 4. Results And Analysis

### 4.1 Soil Laboratory Testing Results

Laboratory testing conducted is a test to determine the soil physical properties (index properties) that consist of Sieve Analysis, Atterberg Limits Test and Standard Compaction Test to gain compaction parameter values. The test results of soil samples are presented in table 2, while the statistical data shown in table 3.

**Table 2.** Testing Result of Soil Samples

No	Soil Classification		Fines (%)	LL (%)	PL (%)	PI (%)	$\gamma_d$ max (gr/cm <sup>3</sup> )	Wopt (%)
	AASHTO	USCS						
1	A-4	SC	42,01	27,20	18,65	8,55	1,462	21,23
2	A-4	CL	58,74	29,37	20,08	9,29	1,423	22,67
3	A-6	CL	59,50	29,62	18,60	11,02	1,421	22,74
4	A-4	SC	43,83	26,60	17,77	8,83	1,466	20,98
5	A-4	SC-SM	40,41	26,11	19,27	6,84	1,473	20,88
6	A-4	SC	48,77	29,10	21,52	7,58	1,444	22,25
7	A-4	CL	50,90	28,63	20,25	8,37	1,450	21,98
8	A-4	CL	51,39	28,58	19,87	8,71	1,451	21,74
9	A-4	SC	40,33	26,01	17,45	8,56	1,499	19,76
10	A-4	CL	59,94	30,38	22,17	8,22	1,421	23,16
11	A-4	SC	45,70	31,56	22,47	9,09	1,415	24,33
12	A-4	SC	39,81	25,83	16,59	9,24	1,502	18,40
13	A-4	SC	46,04	27,59	18,44	9,16	1,460	21,52
14	A-4	SC	46,03	27,36	18,94	8,43	1,461	21,50
15	A-6	CL	51,81	29,08	17,21	11,87	1,445	22,75
16	A-4	CL	62,17	33,10	22,86	10,23	1,398	26,51
17	A-4	SC	44,58	28,14	18,39	9,76	1,454	21,59
18	A-4	CL	51,77	29,04	20,17	8,87	1,446	22,24
19	A-4	SC	44,55	27,86	19,81	8,05	1,459	21,55
20	A-4	SC	44,64	28,49	19,65	8,84	1,451	21,98
21	A-4	SC	43,33	26,69	17,76	8,94	1,478	20,44
22	A-4	SC	46,02	27,55	18,13	9,42	1,466	21,91
23	A-4	CL	59,54	28,22	18,19	10,03	1,421	22,90
24	A-4	CL	59,81	30,50	21,43	9,07	1,422	23,50
25	A-4	SC	44,62	28,34	19,71	8,63	1,453	21,16
26	A-4	CL	59,83	30,25	21,13	9,12	1,426	23,20
27	A-4	SC	43,03	25,52	17,11	8,41	1,495	18,32
28	A-4	SC	49,72	28,82	20,22	8,60	1,447	22,75
29	A-6	CL	61,66	32,02	21,02	11,00	1,415	25,65

by :	30	A-4	CL	51,78	29,08	20,09	9,00	1,443	22,37	$\gamma_{d \max}$
	No	Soil Classification		Fines	LL	PL	PI	$\gamma_{d \max}$	Wopt	=
		AASHTO	USCS	(%)	(%)	(%)	(%)	(gr/cm <sup>3</sup> )	(%)	
	31	A-4	CL	51,95	28,72	20,39	8,33	1,448	22,24	
	32	A-4	CL	57,79	29,34	21,12	8,23	1,439	23,96	
	33	A-4	SC	47,52	28,04	18,74	9,30	1,458	22,55	
	34	A-4	SC	48,91	26,83	17,77	9,05	1,445	22,07	
	35	A-4	CL	59,83	30,19	20,51	9,68	1,427	23,26	
	36	A-6	CL	61,82	33,11	21,72	11,39	1,384	24,48	
	37	A-4	CL	57,70	29,35	19,62	9,73	1,439	22,91	
	38	A-4	CL	51,74	29,00	19,23	9,77	1,440	21,25	
	39	A-4	SC	49,84	29,47	19,76	9,72	1,437	23,25	
	40	A-4	CL	57,84	29,51	19,85	9,66	1,437	22,35	
	41	A-4	CL	51,78	29,08	20,79	8,29	1,442	22,60	
	42	A-4	SC	48,69	28,63	20,30	8,33	1,449	22,13	
	43	A-4	CL	59,84	31,01	22,03	8,98	1,421	24,05	
	44	A-6	CL	61,77	32,75	21,10	11,66	1,390	25,20	
	45	A-4	CL	51,89	29,04	19,96	9,08	1,443	23,38	
	46	A-4	CL	57,84	29,37	20,22	9,16	1,439	21,89	
	47	A-4	SC	44,86	28,56	19,75	8,81	1,450	23,17	
	48	A-4	CL	57,79	29,31	19,67	9,64	1,440	22,67	
	49	A-4	SC	48,64	28,86	20,42	8,43	1,446	22,79	
	50	A-4	CL	57,78	29,58	19,77	9,82	1,436	22,26	

Maximum dry unit weight; Wopt = Optimum water content; Fines = Fines percentage;  
LL = Liquid Limit; PL = Plastic Limit dan PI = Plasticity Index

**Table 3.** The Statistic of Soil Samples Testing Result

Variable	Range	Average
Fines Percentage (%)	39,81 – 62,17	51,56
Liquid Limit (%)	25,52 – 33,11	28,93
Maximum dry unit weight (gr/cm <sup>3</sup> )	1,384 – 1,502	1,444
Optimum water content (%)	18,32 – 26,51	22,41
N = 50		

#### 4.2 Soil + Cement Laboratory Testing Results

After the soil mixed with cement, then make a test with soil samples without cement. The test results of soil samples plus cement are presented in table 4, while the statistical data given in table 5.

**Table 4.** Testing Results of Soil Samples + Cement

No	PS (%)	Fines (%)	LL (%)	PL (%)	PI (%)	$\gamma_{d \max}$ (gr/cm <sup>3</sup> )	Wopt (%)
1	2	42,34	26,67	19,00	7,66	1,465	20,60
2	2	58,89	29,00	20,02	8,98	1,425	22,07
3	2	60,11	29,44	18,72	10,72	1,424	22,17
4	2	44,14	26,13	18,08	8,05	1,469	20,36
5	2	41,06	25,62	19,60	6,02	1,476	20,25
6	2	49,03	28,67	21,81	6,86	1,446	21,63
7	2	51,72	28,09	20,62	7,48	1,453	21,40
No	PS (%)	Fines (%)	LL (%)	PL (%)	PI (%)	$\gamma_{d \max}$ (gr/cm <sup>3</sup> )	Wopt (%)
8	2	51,65	28,04	20,23	7,81	1,454	21,14
9	2	40,85	25,49	17,80	7,69	1,503	19,24
10	2	60,42	29,85	22,51	7,35	1,424	22,71
11	4	47,90	30,57	23,13	7,43	1,428	23,43
12	4	41,89	24,88	17,23	7,65	1,520	17,58
13	4	47,75	26,62	19,08	7,54	1,475	20,64
14	4	47,76	26,24	19,68	6,57	1,478	20,76
15	4	53,10	28,59	17,53	11,06	1,460	22,11
16	4	64,59	32,51	23,26	9,25	1,414	25,70
17	4	46,30	27,47	18,82	8,66	1,469	20,81
18	4	53,54	28,03	20,85	7,18	1,464	21,43
19	4	47,02	26,76	20,54	6,22	1,474	20,72
20	4	46,42	27,46	20,34	7,12	1,469	21,09
21	6	47,37	25,00	18,87	6,13	1,507	19,38
22	6	49,22	26,10	19,10	6,99	1,497	20,82
23	6	62,54	27,12	18,93	8,19	1,449	21,98
24	6	63,14	28,96	22,45	6,51	1,454	22,43
25	6	49,18	26,73	20,82	5,91	1,484	20,05
26	6	64,11	28,76	22,12	6,64	1,460	22,14
27	6	47,57	23,74	18,30	5,44	1,548	17,04
28	6	54,66	27,04	21,40	5,64	1,478	21,69
29	6	65,39	31,03	21,68	9,35	1,441	24,67
30	6	54,90	27,56	21,10	6,46	1,474	21,36
31	8	57,71	26,61	21,79	4,83	1,490	20,92
32	8	63,09	27,08	22,61	4,47	1,482	22,59
33	8	53,82	26,17	19,99	6,18	1,504	21,26
34	8	54,44	25,02	18,99	6,03	1,492	20,76
35	8	65,24	28,35	21,73	6,62	1,470	21,99
36	8	67,30	31,90	22,52	9,38	1,424	22,27
37	8	63,55	27,56	20,82	6,74	1,485	21,60
38	8	56,23	27,19	20,44	6,75	1,491	19,95
39	8	55,80	27,39	21,13	6,26	1,489	21,50
40	8	62,71	27,58	21,13	6,45	1,487	20,97
41	10	58,59	26,23	21,70	4,54	1,503	21,04
42	10	55,90	25,70	22,26	3,44	1,513	20,46
43	10	66,56	28,06	23,99	4,07	1,483	22,41
44	10	68,42	31,35	22,03	9,32	1,448	22,71

45	10	58,53	26,39	21,72	4,67	1,513	21,76
46	10	64,32	26,84	21,89	4,95	1,507	20,26
47	10	51,31	25,81	21,58	4,23	1,513	21,45
48	10	64,17	26,80	21,35	5,45	1,504	20,98
49	10	55,86	25,93	22,39	3,54	1,512	21,06
50	10	64,45	26,84	21,59	5,25	1,505	20,59

by :  $\gamma_{d \max}$  = Maximum dry unit weight;  $W_{opt}$  = Optimum water content; Fines = Fines percentage; LL = Liquid Limit; PL = Plastic Limit, PI = Plasticity Index and PS= Percentage of cement addition

**Table 5.** The Statistic of Soil Samples + Cement Testing Results

Variabel	Range	Average
Fines Percentage (%)	40,85 – 68,42	55,25
Liquid Limit (%)	23,74 – 32,51	27,46
Maximum dry unit weight (gr/cm <sup>3</sup> )	1,414 – 1,548	1,476
Optimum water content (%)	17,04 – 25,70	21,28
N = 50		

The next step is make statistic analysis to determine the correlation between compaction parameters with a value of index properties and the addition of cement. The values of index properties used is the percent of fine grains (fines) and Liquid Limit (LL). The regression relation using one variable and two variables were analysed with Microsoft Excel program 2007 while the regression relation using three variables were analysed with SPSS version 16. The linear regression models were used to determine the relation between compaction parameters with the value of index properties and the addition of cement.

#### 4.3 The Relation Between Compaction Parameter Value with Index Properties

By using regression method to determine the relation between compaction parameter values with index properties and the addition of cement, obtained an equations by using Microsoft Excel and SPSS. The equations that form is as follows:

1. Relationship between the maximum dry unit weight ( $\gamma_{d \max}$ ) with fine grains percent (fines) are:

$$\begin{aligned} (\gamma_{d \max}) &= 1.527 - 0.000 * \text{Fines} \\ R^2 &= 0.062 \end{aligned} \quad (9)$$

This means that 6.2% of maximum dry unit weight values can be estimated using linear equations of fine grains percent value.

2. Relation between maximum dry unit weight ( $\gamma_{d \max}$ ) with Liquid Limit (LL) are:

$$\begin{aligned} (\gamma_{d \max}) &= 1.855 - 0.013 * \text{LL} \\ R^2 &= 0.739 \end{aligned} \quad (10)$$

This means that 73.9% of the maximum dry unit weight values can be estimated using linear equations of the value of the liquid limit.

3. Relation between maximum dry unit weight ( $\gamma_{d \max}$ ) with the addition of cement percent are:

$$\begin{aligned} (\gamma_{d \max}) &= 1.443 + 0.005 * \text{PS} \\ R^2 &= 0.276 \end{aligned} \quad (11)$$

This means that 27.6% of dry weight of the maximum dry unit weight value can be estimated using linear equations of the value of percent cement addition.

4. Relation between optimum water content ( $W_{opt}$ ) with fine grains percent (fines) are:

$$\begin{aligned} W_{opt} &= 15.371 + 0.106 * \text{Fines} \\ R^2 &= 0.347 \end{aligned} \quad (12)$$

This means that 34.7% moisture content optimum value can be estimated using linear equations of fine grains percent value.

5. Relation between optimum water content (Wopt) with liquid limit (LL) are:

$$W_{opt} = 3.504 + 0.647 * LL \quad (13)$$

$$R^2 = 0.701$$

This means that 70.1% moisture content optimum value can be estimated using linear equations of the liquid limit value.

6. Relationship optimum water content (Wopt) with the addition of cement percent are:

$$W_{opt} = 21.223 + 0.009 * PS \quad (14)$$

$$R^2 = 0.000$$

This means that the 0% value optimum moisture content can be estimated using a linear equation of a percent cement additional value.

Then combined the relation between compaction parameter values using two variables index properties and percent cement addition as follows:

1. Relation between the maximum dry unit weight ( $\gamma_d$  max) with fine grains percent (fines) and Liquid Limit (LL) are: ( $\gamma_d$  max) = 1.867 + 0.001 \* Fines - 0.017 \* LL

$$(15)$$

$$R^2 = 0.812$$

This means that 81.2% of maximum dry unit weight value can be estimated using multiple linear equation of fines percent and liquid limit value.

2. Relation between the maximum dry unit weight ( $\gamma_d$  max) with fine grains percent (fines) and percent cement addition (PS) are:

$$(\gamma_d \text{ max}) = 1.588 - 0.003 * \text{Fines} + 0.011 * PS \quad (16)$$

$$R^2 = 0.743$$

This means that 74.3% of maximum dry unit weight value can be estimated using multiple linear equation of fine grains percent value and the percent of cement addition.

3. Relation between the maximum dry unit weight ( $\gamma_d$  max) with Liquid Limit (LL) and the percent of cement addition (PS) are:

$$(\gamma_d \text{ max}) = 1.804 - 0.013 * LL - 0.004 * PS \quad (17)$$

$$R^2 = 0.905$$

This means that 90.5% of of maximum dry unit weight value can be estimated using multiple linear equation of fine grains percent value and the percent of cement addition.

4. Relation between optimum water content (Wopt) with fine grains percent (fines) and Liquid Limit (LL) are:  $W_{opt} = 3.813 + 0.033 * \text{Fines} + 0.569 * LL$

$$(18)$$

$$R^2 = 0.725$$

This means that 72.5% water content optimum value can be estimated using multiple linear equation of fines percent value and liquid limit.

5. Relation between optimum water content (Wopt) with fine grains percent (fines) and percent of cement addition (PS) are:

$$W_{opt} = 13.974 + 0.159 * \text{Fines} - 0.244 * PS \quad (19)$$

$$R^2 = 0.507$$

This means that 50.7% of the value of the optimum water content can be estimated using multiple linear equation of fines percent value and percent of cement addition.

6. Relation optimum water content (Wopt) with liquid limit (LL) and the percent of cement addition (PS) are:  $W_{opt} = 2.652 + 0.663 * LL + 0.070 * PS$

$$(20)$$

$$R^2 = 0.721$$

This means that 72.1% moisture water optimum value can be estimated using multiple linear equation of liquid limit and percent of cement addition.

From the results of multiple linear regression known that the relation between the value of compaction parameters with a combination of two variables of percent fine grains (fines), Liquid Limit (LL) and the percent of cement addition (PS) is strong enough. It can be seen from the value of  $R^2$ . With  $R^2$  model which in good category can get the relation with three variables to estimate the maximum dry

unit weight and optimum water content. Relations between compaction parameter values using three variables are as follows:

1. For maximum dry bulk density values are:

$$(\gamma_d \text{ max}) = 1.782 - 0.011 * LL + 0.000 * \text{Fines} + 0.006 * PS \quad (21)$$

$$R^2 = 0.915$$

This means that 91.5% maximum dry unit weight can be estimated with a range of 95% using a variable of liquid limit, percent fines, and the percent of cement addition.

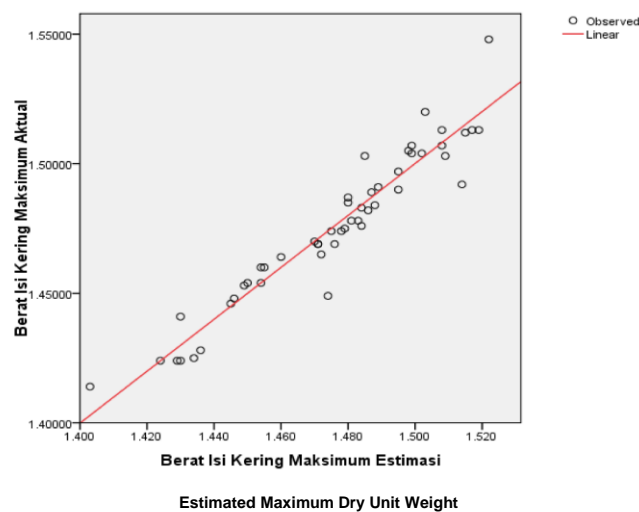
2. For optimum water content values are:

$$W_{opt} = 3.441 + 0.594 * LL + 0.025 * \text{Fines} + 0.024 * PS \quad (22)$$

$$R^2 = 0.726$$

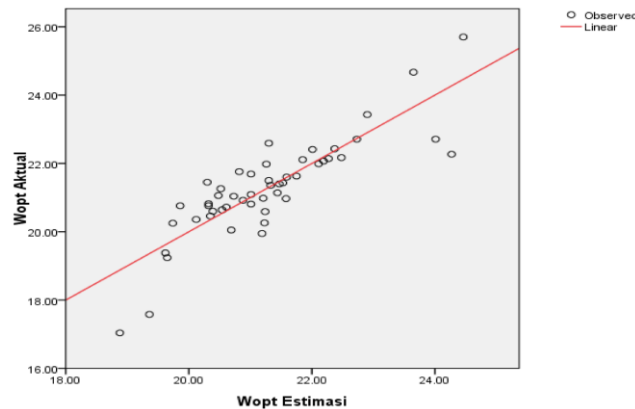
This means that 72.6% optimum moisture content can be predicted with a range of 95% using a variable of liquid limit, percent fines, and the percent of cement addition.

Figure 1 and figure 2 show the correlation of estimated maximum dry unit weight with actual maximum dry unit weight and estimated optimum water content with the actual optimum water content. From the equation obtained that level of accuracy showed by the value of  $R^2 = 91.5\%$  and  $72.6\%$ . With a value of  $R^2$  show that the equations using three independent variable, and they are the percent fines, liquid limit and percent addition of cement can be used in estimating the value of the parameter compaction.



**Figure 1.** Relation Graphic of the actual maximum dry unit weight with the estimated maximum dry unit weight.





**Figure 2** Relation Graphic of the actual optimum water content with the estimated optimum water content.

## 5. Conclusion

From the results of laboratory testing and analysis of data obtained following matters:

1. Statistical analysis using linear equations can be used in estimating the value of the parameter compaction.
2. The maximum dry unit weight ( $\gamma_d$  max) and Wopt has a significant relation to the percent of fines, the liquid limit and the percent of cement addition.
3. The equations that have resulted from this research has an excellent safety range for maximum dry unit weight and also for the optimum water content. This can be proof from the  $R^2$  value generated.

## References

- [1] Chen L and Lin D F 2009 Stabilization treatment of soft subgrade soil by sewage sludge ash and cement *Journal of Hazardous Materials*, **162**(1) 321-327
- [2] Park T (2003) Application of construction and building debris as base and subbase materials in rigid pavement *Journal of Transportation Engineering* **129**(5) 558-563
- [3] Aadil N, Riaz S dan Waseem U 2014 Stabilization of subgrade soils using cement and lime: a case study of Kala Shah, Kaku Lahore, Pakistan *Pakistan Journal Of Science* **66** (1) March, 2014.
- [4] Gu F, Sahin H, Luo X, Luo R., and Lytton, R L 2014 Estimation of resilient modulus of unbound aggregates using performance-related base course properties. *Journal of Materials in Civil Engineering* **27**(6) 04014188
- [5] Solanki P, Zaman M, and Dean J 2010 Resilient modulus of clay subgrades stabilized with lime, class C fly ash, and cement kiln dust for pavement design. *Transportation Research Record: Journal of the Transportation Research Board* (2186) 101-110.