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The Use of PT Petro Kimia's by-Product Gypsum as Fill Materials

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***Abstrak*—Gypsum is a by-product of the Phosphoric Acid factory PT Gresik Petrochemicals; it is produced around 1,200,000 tons/year. In order to reduce the amount, an effort needed to use gypsum as fill materials. For this purpose, the problem needs to be considered is that gypsum should not contain substances that harmful to the environment and meet the fill materials requirements. In order to answer all these questions, chemical tests were carried out to determine its heavy metal content. Gypsum plasticity and its particle size distribution were determined by conducting Atterberg limit and sieve analysis tests. Compaction test and CBR test were also carried out to determine the density and its strength. Those results were then analyzed using "The Fifteen Point Method" to obtain a relationship curve between dry density (γd) and soaked-CBR. This curve was important to determine the soaked-CBR that can be achieved by gypsum materials in the field with different compaction energy 90%, 95%, and 100% of maximum compaction energy. Chemical test result shows that all heavy metals content in gypsum material are far below the regulatory limit; therefore, it is safe for the environment. Besides, Gypsum is non-plastic (NP) material and it is classified as A-4 (AASHTO) or SM (USCS); it means that Gypsum is very good for fill materials and safe to the environment. In addition, the result from the Fifteen Point Method shows that the minimum soaked CBR value is 13% achieved by using 90% of maximum compaction energy with 30-40 % of water content. It means that the gypsum material can be used as selected fill material because it fulfils its requirement where IP<6% and soaked CBR>10%.**

***Kata Kunci*—By-Product, CBR, Fill Materials, Gypsum, Soil Compaction.**

I. PENDAHULUAN

PT *Petrokimia* has a by-product of which the volume is quite large; it is gypsum which is the result of waste from the Phosphoric Acid factory of PT. Petrochemical *Gresik*, East Java, Indonesia. The rate of gypsum produced annually is quite large at 1,200,000 tons/year. Such a large amount piled up at *PT Petrokimia's* shelter. In accordance with Government Regulation No. 101 of 2014 concerning B3-Waste Management [1], gypsum can be classified as a B3 waste categorized as special specifications because the amount exceeds the normal threshold. Because of this, petrochemical needs solutions to solve this gypsum buildup problem. One alternative solution that had been done is to make gypsum as a backwater material that was packaged in the form of a product so that the factory is not considered to sell its waste. In addition to reduce the amount of gypsum waste that has accumulated, it can also be used as fill materials. For this purpose, however, the material has to be able to fulfill the requirement as fill material, that is, its strength and its plasticity; besides, it has to be environmentally safe. For this reason, this research is conducted in order to proof that gypsum is safe for the environment and fulfills the fill material requirement. In other words, gypsum must meet technical and environmental aspects as fill material.

II. METHOD

A. Parameters of Physical and Engineering Properties of Gypsum Materials

Parameters of physical and engineering properties of gypsum needed for this study are specific gravity, plasticity, particle-size distribution, maximum dry density, optimum moisture content, and the value of soaked California Bearing Ratio (soaked-CBR). In addition, parameter dry density, optimum moisture content, and the value of California Bearing Ratio (CBR). In addition, parameter of shear strength is also needed in this study to determine gypsum bearing capacity.

B. Testing Used to Determine Physical Properties and Heavy Metals Content in Gypsum Materials

The testing standards used are as follows:

1. SNI 03-1964-1990 to determine Specific Gravity [2];
2. SNI 03-1966-1990 to determine Plastic Limit [3];
3. SNI 03-1967-1990 to determine Liquid Limit [4];
4. SNI 03-3422-1994 to determine shrinkage limit [5]:
5. SNI 03-3423-1994 [6] and SNI 03-1968-1990 [7] to determine particles size (Hydrometer test and sieve analysis);
6. AASHTO T-27-74 [8] and ASTM C-130-46 [9] to classify the material
7. SNI 03-3637-1994 to determine unit weight [10];
8. SNI 03-1965-1990 to determine water content [11];
9. SNI 03-1742-1989 [12] and SNI 03-1743-1989 [13] to determine soil density;
10. SNI 03-1744-1989 to determinate CBR value [14];
11. TCLP test used to determine heavy metal content [15]

C. The Fifteen Point Method to Obtain A Relationship Curve Between Dry Density (γd) and Soaked CBR

The "fifteen point method" is method to analyze some parameters (density, moisture content, and CBR values) in order to obtain a relationship curve between dry density (γd) and CBR. In this study, gypsum was compacted by using 13 blows/layer, 27 blows/layer, and 56 blows/layer that were comparable to 90%, 95%, 100% energy used for modified Proctor compaction test, respectively. By performing the compaction test, the maximum dry density (MDD) and its

Table 1.
TCLP test result gypsum materials

Test Description	Unit	Result	Regulatory Limit	
			TCLP-A	**TCLP-B**
Anorganic Parameters:				
Natimony, Sb	mg/L	< 0.00007	6	1
Aresenic, As	mg/L	< 0.02	3	0.5
Barium, Ba	mg/L	1.123	210	35
Berilium, Be	mg/L	< 0.002	4	0.5
Boron, B	mg/L	< 0.01	150	25
Cadmium, Cd	mg/L	0.054	0.9	0.15
Hexavalent Chromium, Cr^{6+}	mg/L	< 0.01	15	3
Copper, Cu	mg/L	0.094	60	10
Lead, Pb	mg/L	0.44	3	0.5
Mercurry, Hg	mg/L	< 0.00002	0.3	0.05
Molybdenum, Mo	mg/L	< 0.002	21	3.5
Nickel. Ni	mg/L	0.24	21	3.5
Selenium, Se	mg/L	< 0.0002	3	0.5
Silver, Ag	mg/L	< 0.005	40	5
Zinc, Zn	mg/L	0.21	300	50

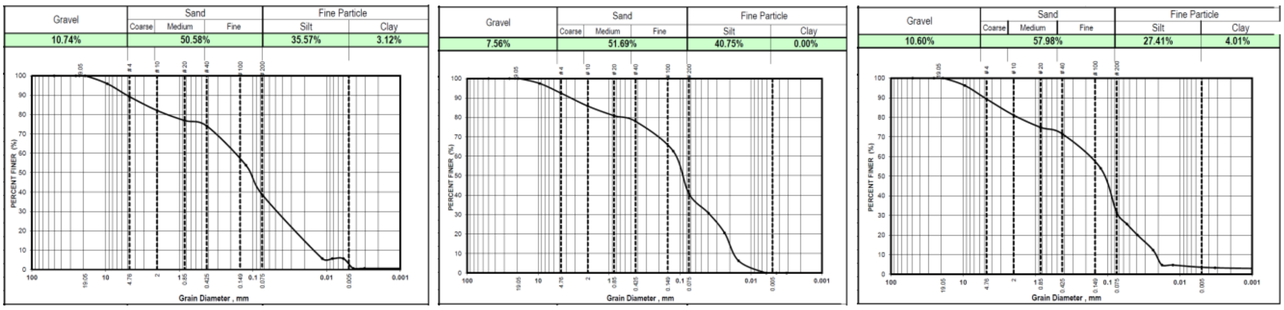

Figure. 1. Results of Sieve analysis and Hydrometer tests of 3 gypsum samples.

Table 2.
Gypsum's Particle-size Distribution Summary

Particle type	Unit	Percentage
Gravel	%	9.63
Sand	%	53.42
Silt	%	34.57
Clay	%	2.38

Table 3.
Gypsum's Materials in Initial State

Parameters	Unit	Value
γt	t/m^3	1.056
γd	t/m^3	0.819
Wc	%	28.97
Sr	%	32.73
e		2.64
Gs		2.98
Liquid Limit		NP
Plastic Limit		NP

Table 4.
Dry Density and Water Content of

56 Blows**		27 Blows		13 blows*	
Wc (%)	γdry (t/m^3)	Wc (%)	γdry (t/m^3)	Wc (%)	γdry (t/m^3)
15.37	1.24	28.46	1.225	30.19	1.149
20.11	1.32	32.02	1.304	35	1.22
29.28	1.446	35.84	1.338	38.88	1.266
32.51	1.396	37.16	1.337	39.78	1.27
43.42	1.347	47.66	1.25	40.52	1.257
				45	1.21

Note: ** equals to Modified Proctor
* equals to Standard Proctor

optimum water content (OMC) were Determined. Each of compaction sample was also determined its soaked-CBR value by performing the CBR test. In order to get the soaked-CBR, the compacted samples were soaked for 4 days prior to CBR tests were carried out. From the compaction and CBR curves obtained, curve of (γd vs soaked-CBR) of gypsum material was able to be constructed by using the "fifteen point method" [16].

III. RESULT AND DISCUSSION

A. *Chemical Content*

The TCLP test was carried out at the ITS Chemical Engineering Laboratory. From the test results as shown in **Table 1**, it can be seen that all heavy metals content in gypsum material are very small and far below the regulatory limit required by the EPA and SNI (TCLP-A and TCLP-B). It means that the gypsum material by product of PT. Gresik Petrochemicals is very safe to be used as fill material.

B. *Physical Properties*

Sub The results of sieve analysis and hydrometer tests are given in **Figure 1**; the percentages of gravel, sand, silt, and clay are given in **Table 2**. The data given in **Figure 1** and **Table 2** show that the gypsum material is dominated by fine fractions where particles passed sieve # 200 (silt and clay fractions) is 36.95%.

The other physical properties of gypsum material in the initial condition (in *PT Petrokimia's* shelter) are given in **Table 3**. The results show that gypsum material studied is non-plastic (NP) material. Its specific gravity is high that is 2.98 but the unit weight is very small because the sample was taken from the dumping area of *PT Petrokimia* at *Gresik*.

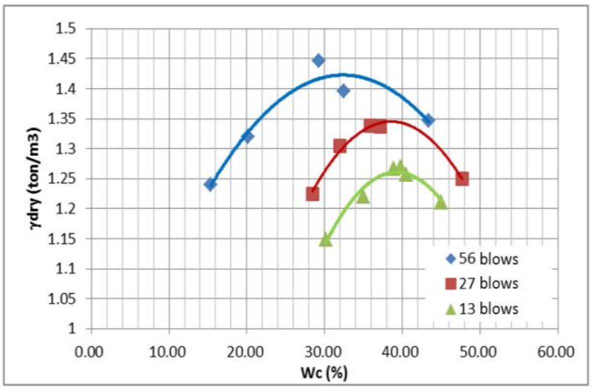

Figure. 2. Compaction curves obtained from three different compaction energies applied

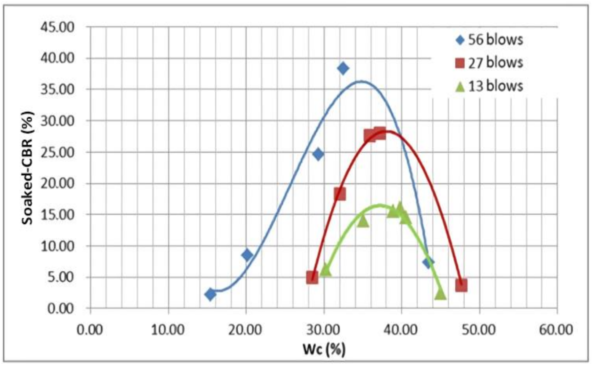

Figure 3. Curves of soaked-CBR vs water content of Gypsum compacted at three different compaction energies applied.

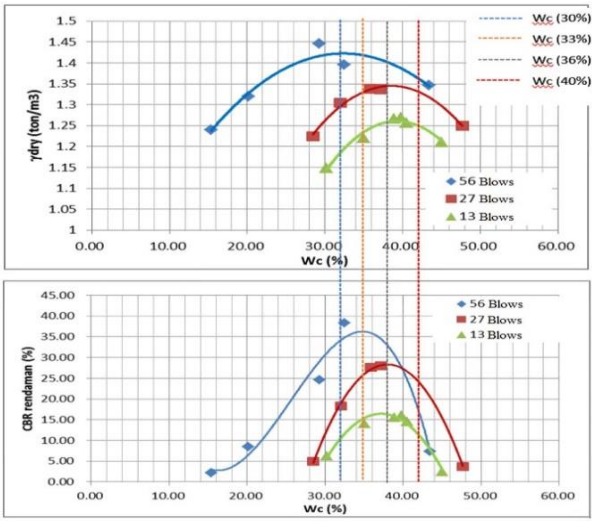

Figure 4. Application of the fifteen point method to determine the values of dry density (γd) and soaked CBR at the same water content

Based on the data given in **Table 2** and **Table 3**, Gypsum can be classified as:

1. Well graded sand / SW (USCS); or
2. A-2-4 soil, with Group Index = 1 (AASHTO) etc.

As well graded sand or A-2-4 soil, it is known that the gypsum material studied is non-plastic material that is dominated by sandy and relatively non-dense materials. This indicates that gypsum material does not easily change its nature when exposed to water; therefore, gypsum material is an excellent material to be used as a fill material.

Table 5.
MDD and OMC of Gypsum Compacted at 3 Different Compactions Energies

Parameters	13 blows	27 blows	56 blows
γd_{max} (t/m^3)	1.27	1.35	1.425
Wc opt (%)	38	36	32
Wc opt ± 2%	36 - 40	34 - 38	30 - 34

Table 6.
Soaked-CBR and Water Content of Gypsum Compacted at Different Compaction Energies

56 Blows**		27 Blows		13 blows*	
Wc (%)	CBR (%)	Wc (%)	CBR (%)	Wc (%)	CBR (%)
15.37	2.25	28.46	4.91	30.19	6.24
20.11	8.5	32.02	18.31	35	14
29.28	26.64	35.84	27.64	38.88	15.48
32.51	38.29	37.16	28.05	39.78	16.07
43.42	7.33	47.66	3.75	40.52	14.57
				45	2.5

Note: ** Equals to Modified Proctor
* Equals to Standard Proctor

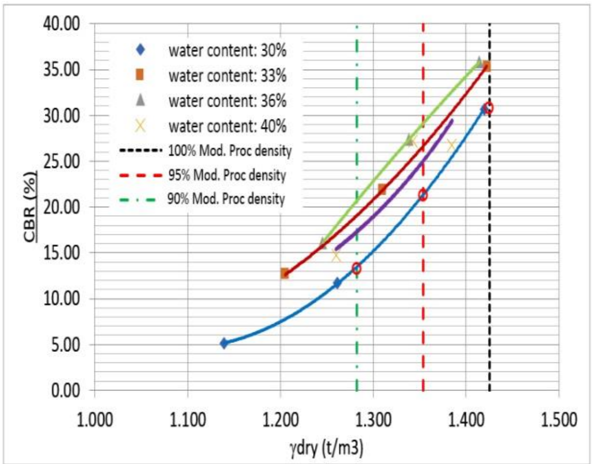

Figure 5. The curves of soaked-CBR vs dry density of gypsum material at different water contents (Wc).

C. The Effect of Compaction to the Maximum Dry Density and Optimum Water of Gypsum Material

The compaction test was performed in the Soil Mechanics laboratory in order to get the maximum dry density/MDD (γd) and the Optimum Moisture Content/OMC (Wc-opt). Those values determined from the relationship curve between dry density (γd) and Water content (Wc) as shown in Figure 2; the values of MDD and OMC are given in Table 4. They show that the higher the compaction energy used, the higher the value of MDD (γd) achieved but the lower the OMC obtained. The values of MDD and OMC achieved by 3 variations (lowest, middle, and highest) of compaction energies used in this study can be seen in Table 5. The lowest compaction energy (equivalent to the Standard Proctor compaction test) is represented by 13 blows and has value of γdmax ≈ 90% γdmax. The compaction energy by using 27 blows has value of γdmax ≈ 95% γdmax. While the highest compaction energy that is represented by 56 blows is equivalent to the Modified Proctor compaction test has value of γdmax ≈ 100% γdmax.

Table 7.
Soaked-CBR and Dry Unit Weights at Four Different Water Content of Gypsum n compacted at 3 different compaction energies

Wc (%)	**56 Blows**		**27 Blows**		**13 blows**	
	γdry (t/m³)	**CBR (%)**	**γdry (t/m³)**	**CBR (%)**	**γdry (t/m³)**	**CBR (%)**
30	1.419	30.65	1.262	11.69	1.139	5.15
33	1.422	35.36	1.310	21.82	1.205	12.61
36	1.414	35.80	1.338	27.29	1.246	16.13
40	1.385	26.80	1.343	27.24	1.260	14.68

Table 8.
The minimum value of soaked-cbr at water content 30% till 40% that can be achieved with 3 different compaction energy

Parameters	**90% Mod. Proctor density**	**95% Mod. Proctor density**	**100% Mod. Proctor density**
CBR minimum (%)	13	21	31
Recommended Wc (%) for Compaction	30 - 40	30 - 40	30 - 40

D. The Effect of Compaction Energy to the Soaked-CBR of Gypsum Materials

CBR test was also carried out in the Soil Mechanics laboratory in order to know the soaked-CBR maximum that could be achieved by the gypsum material. The soaked-CBR value is determined from the relationship curve between water content (Wc) and soaked-CBR values as shown in Figure 3; the results of soaked-CBR are given in Table 6. The results show that the soaked-CBR of Gypsum has similar behavior with its density where the higher the compaction energy used for compaction, the higher the soaked-CBR value achieved but the lower the Optimum Moisture Content/OMC obtained.

E. The Relationship Between Gypsum Density and Soaked-CBR

By having 2 (two) relationship curves, those are γd vs Wc (Figure 2) and soaked-CBR vs Wc (Figure 3), the relationship between Wc, γd, and soaked-CBR can be determined by using the *"Fifteen Point Method"*. The relationship between water content (Wc), density (γd), and soaked-CBR can be used to determine the minimum value of soaked-CBR when the gypsum material is compacted in the field by using difference water content and difference compaction energy.

For this purpose, water content at range of $W_{c\text{-}opt} \pm 2.0\%$ (30% - 40%) is chosen; in that range, 4 (four) different values of water content (Wc) are determined, those are 30%, 33%, 36%, and 40%. Through those 4 (four) values of water content chosen, draw 4 (four) vertical lines until intersect the compaction and soaked CBR curves as shown in Figure 4. From the intersection between those four lines and the curves, the values of dry density and soaked-CBR at the same water content (W_c) can be determined as summarized in Table 7. Afterwards, those values are plotted to construct curves that have relationship between dry density and soaked-CBR as shown in Figure 5.

In order to determine the minimum value of soaked-CBR that can be achieved by different compaction energy, three lines related to 90%, 95%, 100% of maximum compaction effort are plotted at curves (Υ_d vs soaked-CBR) in Figure 5. From the intersection between the lines and those curves, the minimum value of soaked-CBR that can be achieved by using 90%, 95%, 100% of maximum compaction effort are 13%, 21%, and 31%, respectively. These results show that the gypsum material from PT Petrochemical *Gresik* has very good requirements as borrowed selected material although it only compacted with 90% of maximum compaction effort. It fulfils the PUPR requirement [17] as selected fill material where the soaked-CBR value at least 10% and its Plasticity Index, IP <6%. If the Gypsum material compacted with 100% of maximum compaction effort, the minimum soaked-CBR value of 31% can be achieved. It means that the Gypsum can be used as subbase course materials if it is compacted with the maximum compaction effort; the requirements from PUPR for subbase course soil is soaked-CBR> 25% and IP<6%.

IV. CONCLUSION

Gypsum material is safe for the environment; all the heavy metal contained in gypsum material are far below the minimum requirement recommended by the EPA and SNI. Gypsum is non plastics (NP) material and classified as:(a)Well graded sand / SW (USCS); or; (b)A-2-4 soil, with Group Index = 1 (AASHTO) .Maximum Dry Density / MDD of gypsum material and optimum moisture content (OMC: optimum moisture content) varies depending on the compaction effort used; the MDD and OMC obtained are as follows;(a)MDD=1.27 tons/m3 and OMC=38%, if compacted with 90% of maximum compaction effort that is equivalent to the energy of Standard Proctor test;(b)MDD=1.35 tons/m3 and OMC=36%, if compacted with 95% of maximum compaction effort; (C)MDD=1.425 tons/m3 and OMC=32%, if compacted with 100% of maximum compaction effort that is equivalent to the energy of Modified Proctor test. The minimum values of soaked-CBR obtained with different compaction effort applied are as follows: (a)Minimum soaked-CBR=13% at Wc=30%-40% if energy applied for compaction is 90% of maximum compaction effort; (b)Minimum soaked-CBR=21% at Wc=30%-40% if energy applied for compaction is 95% of maximum compaction effort; (c)Minimum soaked-CBR=31% at Wc=30%-40% if energy applied for compaction is 100% of maximum compaction effort. The Gypsum material can meet the minimum PUPR requirement as a selected material; it has IP <6% and minimum soaked CBR > 10% although it is compacted only with 90% of maximum compaction energy.The Gypsum material can be used as subbase course materials if it compacted with maximum compaction effort; it has value of soaked-CBR > 25% and IP <6%.

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