

DESIGN OF IMPROVED LIME EXPANSIVE SOIL FOR EMBANKMENT OF FLEXIBLE PAVEMENT

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ABSTRACT: The problem of the pavement structure on an expansive subgrade has to be found in some area which the reason the road surface will failure. Expansive soil experiences periodic swelling and shrinkage during the alternate wet and dry environments. The lime as the additive substance can reduce the swell potential and increase the bearing capacity of expansive soil was well known. In this study, the expansive natural soil and the improved lime soil have been used as landfill for subgrade of the pavement structure. Numerical modeling of flexible pavement constructed on expansive soil would apply for investigate settlement and strain to estimate failure which is always occurring. Based on FEM analysis using a computer program, the results show that the application for embankment with a height of 5m with the traffic load is considered a static load, resulting in a reduction in the potential damage where compressive strain occurs on the road surface under traffic load. The lime also reduced the total settlement.

Keywords: Expansive, Lime, Embankment, Traffic, Strain

1. INTRODUCTION

In a developing country like Indonesia has a large area. It needs to design the road to connect a region to another region. The Ministry of Energy and Mineral Resources (ESDM) propose to build production facilities to increase natural gas production capacity in Ngasem Bojonegoro. The road was one of the facility had been prepare for delivery.

The development area of the Jimbaran - Tiungbiru Unitization Gas Field is located in a rock formation that contains a lot of clay minerals so that the weathering soil is expansive or has a high shrinkage and low carrying capacity. For this reason, the soil is needed to improve on the surface, so that the infrastructure built on it is not damaged quickly and can support the buildings above it.

This research includes testing of natural soil, improvement lime natural soil in the laboratory and slope stability analysis. The results of this investigation are expected to recommend to use the improve soil as the material of embankment in road construction.

The expansive soil generally was fine granular soil whose montmorillonite mineral content. This mineral is more attractive to water cause ionic arrangement. If the soil absorbs water, it will increase in volume with swelling pressure that reason of the swelling, whereas if it experiences drying until the water content is low, volume shrinkage will occur accompanied by cracks in the soil layer as shown in Fig. 1.



Fig.1 The expansive soil on dry condition

The rocks on the surface of the location are claystone from the Tongue Formation. The clay found in greenish gray, slightly sandy, locally encountered carbonate sandstone lenses. The weathered soil clay is dark gray, with white spots. During the dry season it has been found many fractures with a width of about 5 cm, and during the rainy season, it was very plastic.

Some studies conducted for remedial measures such as improvement with soil replacement, lime [4], cement [13], gypsum[14], fly ash [12]. In addition to providing ameliorant, geogrid reinforcement can improve also used [16].

The use of FEM computer programs to analyze stresses and strain using a computer is well known because it can handle non-linear material conditions. One of the cases often analyzed is the embankment slope for road structures in which the LEM method used to analysis. Calculation of safety factor using these two methods gives a value that is not much different [4]. In more specific cases, numerical modeling flexible pavement on expansive soil [1,7]

has been carried out. Traffic loads are expressed as static loads for a two-wheeled one-axle truck model [8]. Expansive soil modeling as soft soil with saturated drained conditions gives results that are close to field conditions in the calculation of decreases that occur [8].

2. MATERIAL AND METHODOLOGY

2.1 Materials

2.1.1 General requirements for subgrade preparation

The three most important factors in pavement design are traffic, subgrade, and the influence of water. Also, in the case of pavements that must be built in the area with problematic soil such as peat, expansive soil, and soft soil, the characteristics of the soil concerned is a very important factor because natural subgrade analysis cannot produce pavement with the expected performance

The pavement subgrade must meet the following criteria:

- It must have a minimum soaked CBR
- It was formed correctly, according to the geometric shape of the road;
- well compacted at layer thickness according to requirements;
- insensitive to changes in water content;
- able to support the traffic load of construction.

The subgrade for embankment in this study is expansive, so the soil has been improved with lime. The investigation of natural soil has a soaked CBR value of 4.46% after being mixed with lime has a soaked CBR value of 11.6% which meets the CBR criteria for a minimum value.

2.1.2 Landfill

Materials for ordinary embankment should not be content minerals as the following properties:

1. Organic soil such as OL, OH and Pt soils in the system as well as soil containing foliage, grasses, roots, and garbage.
2. Soil with a very high natural moisture content that is not practically dried to meet the moisture tolerance at compaction.
3. Soils have high and very high shrinkage properties.

The soil embankment consists of a compacted layer or lift of suitable material placed on top of each other until the level of the subgrade surface is reached. The component of embankment construction is the thickness of the layer, material, and degree of compaction that represent in CBR value

In general, the soil for embankment usually has soaked CBR at least 10% in maximum dry density.

The other characteristics are Atterberg Limit and composition. It respects the letter for embankment material to be classified as tolerable its degree settlement such as 1% and its swelling potential less than 3%.

The specification can be reached if the type of material as well-graded rock or gravel or a low plasticity silt-clay. The type of material selected and approved by the Engineer will depend on the steepness of the slopes, dumped material, and the loading traffic.

The expansive soil does not meet qualification as an embankment material due to high plasticity. The soil with low plasticity could be used as an embankment by so that before being used as an expansive landfill material it must be improved. Embankment that uses a material with $LL > 60$, $IP > 35$ or expansive material, further handling is needed, including:

- a. Soil improvement, for example by lime or cement; mixed composition must be based on laboratory test results.
- b. Soil reinforcement, for example with, wooden/bamboo mattresses, or woven geotextile.
- c. Soil replacement by replacing soft soil with selected soil material
- d. Slope geometry, where the slope of the embankment is made slope slightly, minimum V: H = 1: 3, and based on the results of slope stability analysis. The chosen alternative can be a combination of these alternatives and must be based on the analysis of subgrade carrying capacity and stability analysis slope.

2.1.3 Lime improved Soil

The lime commonly used is lime (CaO) as a mixture of mortar as a building material. Lime (CaO) itself comes from limestone (CaCO_3) which is a sedimentary rock composed of minerals calcite and aragonite. Lime is known as a material that has a function as a binding material in the manufacture of walls and pillars. The properties of lime are not brittle, easy and quick harden, workability, good and have the connectivity for stone or brick. Lime minerals may be calcium hydroxide, calcium oxide, and calcium carbonate so that they can cause assistance chemical reactions with clay soil. This base material is distinguished according to the content of the contaminating material, known as:

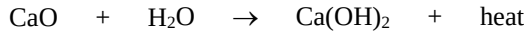
- a. Lime high calcium content of lime CaO levels of more than 95%.
- b. Lime of magnesia is lime which is MgO content more than 5% if the MgO level exceeds 20% then called dolomite.
- c. Lime of hydrolysis is limestone containing soil oxides (Al_2O_3 , SiO_2 , Fe_2O_3).

In this study soil used lime for improving properties such as plastic properties (not brittle), as

a binder that can harden easily and quickly to provide binding strength to clay soil, workability without having to go through a manufacturing process, cheap and easy to obtain.

The phases of chemical processes on soil stabilization using lime are as follows:

- a) Water absorption, exothermic reaction, and expansive reaction; When the lime is mixed on the ground there is water content, there will be a reaction as follows:



The reacting between water and lime will heat up, and at the same time, the volume of lime becomes larger than its original volume, causing a decrease in the water content in the soil.

- b) Ion exchange reactions, clay in the soil content is smooth and negatively charged. Positive ions such as hydrogen ions (H^+), sodium ions (Na^+), calcium ions (Ca^{2+}), and polarized water all attach to the surface of clay granules. If lime is added to the soil with the conditions as mentioned above, the ion exchange immediately takes place, and the surface of the clay grain absorbs the calcium ion derived from the lime solution. Thus, the surface of the clay had lost its repulsion force, and there was cohesion on the grain, increasing the consistency of the soil.
- c) Pozzolan reaction, With time, the silica (SiO_2) and alumina (Al_2O_3) contained in clay with reactive mineral content, will react with lime and form calcium silicate hydrate such as tobermorite, calcium aluminate hydrate $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 12\text{H}_2\text{O}$ and 2CaO gehlenite hydrate. $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2 \cdot 6\text{H}_2\text{O}$. The formation of these chemical compounds lasts continuously for a long time so that the soil becomes hard and not easily fragile (durable).

2.2. Methodology

2.2.1 Traffic Loading

The dimensions, weight of the vehicle and load loaded will cause a compressive force on the vehicle axis. The axial compression force will continue the load on the pavement surface and contribute to road damage. The structure bears the standard axle load (single axis double wheel) with the size and dimensions as stated in Fig. 2. The field of contact between the wheels of the vehicle and the road surface is assumed to be circular[8]. When used vehicle loads are trucks with 80 kN axle loads which are divided into four wheels with the load of each wheel 20 kN (P) with a tire pressure of 650 kPa (q). The contact area of one wheel depends on the load of one wheel and the tire tension. Based on Fig. 2, the contact area of one wheel is obtained as

$$\frac{P}{q} = \pi(0.3L)^2 + 0.4L(0.6L) = 0.522L^2 \rightarrow L = \sqrt{\frac{P}{0.522q}} \quad (1)$$

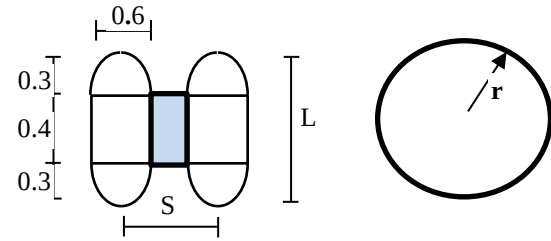
The contact area of the circle's equivalent is

$$\pi r^2 = 2(0.522L^2) + (S - 0.6L) \quad (2)$$

If the distance between the wheels is $S = 0.3 \text{ m}$ and Eq. (1) is substituted in Eq. (2), the equivalent circle area is 0.3146 m^2 with the radius of circle 0.1775 m . The stress acting on the surface of the pavement is

$$\frac{P}{\pi r^2} = 404 \text{ kPa} \quad (3)$$

Because the traffic load is assumed to be a static load, it is multiplied by an impulse factor of 1.2 so that the working stress is 484.8 kPa .



The fig.2 Contact area of the wheels of traffic load

2.2.2 Material Model

There are two models were applied in this study as More-Coulomb for lime improved soil and base layer of pavement and Soft soil model for natural soil.

The yield condition of the Morh-Coulomb model is the Coulomb friction law being general stress. The yield conditions of Mohr-Coulomb are formulated as follows

$$f = \frac{1}{2}(\sigma'_1 - \sigma'_3) + \frac{1}{2}(\sigma'_1 + \sigma'_3) \sin \phi - c \cos \phi \quad (4)$$

Where σ'_1 and σ'_3 are principal stress, c as cohesion and ϕ as internal friction angle. The yield function will form a hexagonal cone in the principal stress space. Beside yield function, there is potential plastic function as Eq.5.

$$g = \frac{1}{2}(\sigma'_1 - \sigma'_3) + \frac{1}{2}(\sigma'_1 + \sigma'_3) \sin \psi \quad (5)$$

The function of plastic potential has the third parameter Ψ as the dilatation angle. Clay mineral represents un-dilatation material. The dilatation of sand depends on density and friction angle. In

addition to the plasticity parameters above, a Young modulus E and Poisson' ratio ν are needed.

Soft soil model is a model that is suitable for soil conditions which are dependent on the state of stress in the compression case. Expansive soil, in this case, is soil where the stress changes according to the water content. The yield function in the triaxial test ($\sigma_3=\sigma_2$) is defined as

$$f = \bar{f} - p_p \quad (6)$$

Where $\bar{f}$ is the function in stress (p' , q) and p_p , pre consolidation stress, is function plastic strain,

$$\bar{f} = \frac{q^2}{M^2(p' + c \cot \phi)} + p' \quad (7)$$

$$p_p = p_p^0 \exp\left(\frac{-\varepsilon_p}{\lambda^* - \kappa^*}\right) \quad (8)$$

Some parameters can be seen in Fig. 3.

The yield function performed an ellipse in the p - q plane, and the parameter M is the height of the ellipse. The parameter λ^* is a modified compression index, which determines the compressibility of soil in primary loading and κ^* is a modified swelling index which determines the compressibility in unloading and reloading of soil.

The value of P_p is determined by volumetric plastic strain following the hardening relation in which P_p^0 is the initial value of pre-consolidation stress.

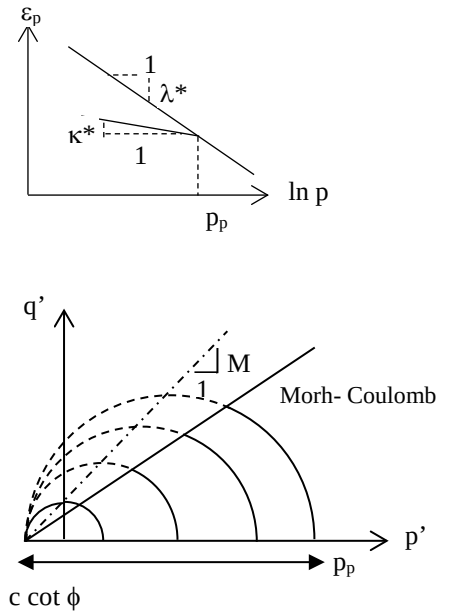


Fig 3 The parameters were used in the soft soil model

The result of the laboratory test are given in Table 1

Table 1 The parameters of the model

Characteristic	Unit	Base	Improved Soil	Natural Soil
Model		MC	MC	Soft Soil
Type of behavior		Drained	Undrained	Undrained
Thickness	m	0,5	5	8
Young Modulus	kPa	140000	8000	5000
Poisson ratio		0,35	0,25	-
Unit Weight	kN/m ³	22	17,5	17,4
Cohesion	kPa	5	126	40
Friction angle	°	40	20	8
Dilatation Angle	°	13	-	-
Compression Index				1,034
Swelling Index				0,21
Void ratio				0,5
un-soaked CBR	%	55	15,5	8,5
Soaked CBR	%		11,6	4,46

2.2.3 Finite Element Analysis of Pavement Structure

The numerical methods as Finite Element present a good estimation for pavement structure.[].in some difference cases model including expansive and soft soil subgrade condition. The used FEM method to calculate stress, strain, and deformation of the material in nonlinear behavior. In this program traffic load (dynamic load) is considered as static load using a ratio factor of dynamic.

In this study, the pavement structure was assumed as two-dimensional axisymmetric problems. The element of the mesh is triangular and will be avoided by the rotation for all nodes. Two degrees of freedom have to consider in defining the boundary condition are applied such as the vertical and horizontal displacement of the node on the bottom plane is fixed, the horizontal displacement in the vertical plane is prevented. The analyses will be done half cross section are pavement structure which is considered in the symmetry plane

The geometric embankment model that will be analyzed is adjusted to field conditions where the maximum embankment height is 5 m, and the groundwater table is very far from the surface, so it is assumed to be 7 m from the surface. The pavement structure is represented by a base layer 50 cm thick as shown in Fig. 4

3. RESULT AND DISCUSSION

3.1. Deformation Behavior

Deformation mesh and settlement of the pavement model by the saturated undrained model for natural soil embankment was shown in Fig. 5. The settlement decrease from 1.2 m to 0.432 m (Fig.6), if landfill was changed to improved lime expansive soil. As previous studied[8] the lime whose Ca^{+2} can displace a cation of low replacing power of expansive soil. The cation exchange causes the bounding in the clay mineral stronger then increase shear strength and decrease swell potential.

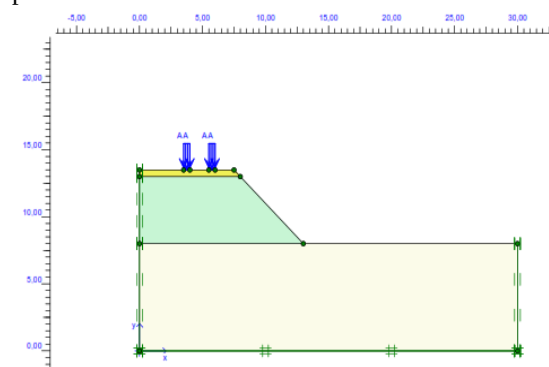


Fig. 4 Geometric model of the pavement system

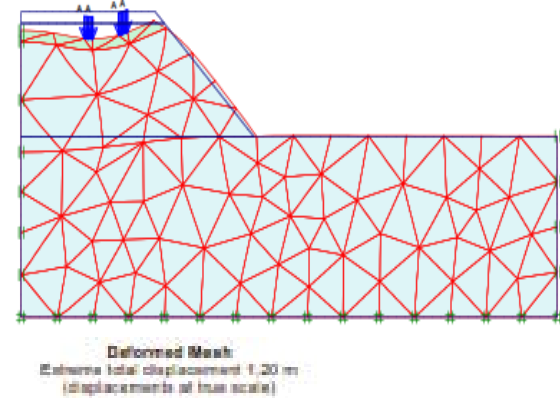


Fig.5 Deformation mesh of expansive natural soil

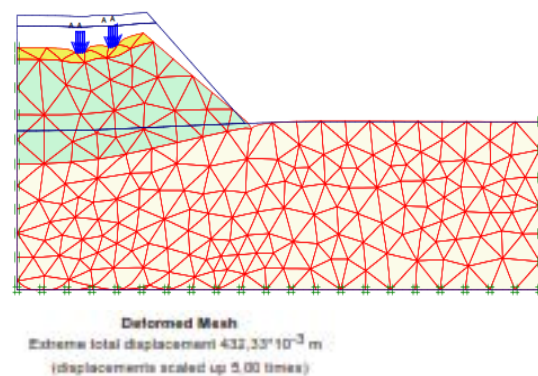


Fig.6 Deformation mesh of improving lime landfill embankment

3.2.Vertical Strain Behavior

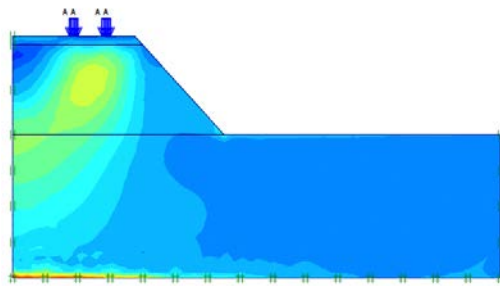
Fig. 7 illustrated the pattern of vertical strains developed in the pavement system corresponding to traffic loading. Distribution of vertical strain in a saturated undrained model gives extreme value in deep layer 33.6 % (underwater table) for natural soil caused by swelling pressure induced by under pavement layer. It is clear that the vertical strain condition could influence premature structure failure[2].

In case of the improved embankment, the maximum value 23,4% (Fig.8) but almost all area on the top and bottom pavement structure were in a compressive strain which decreases the potential of fatigue phenomenon in pavement layer.

4. CONCLUSIONS

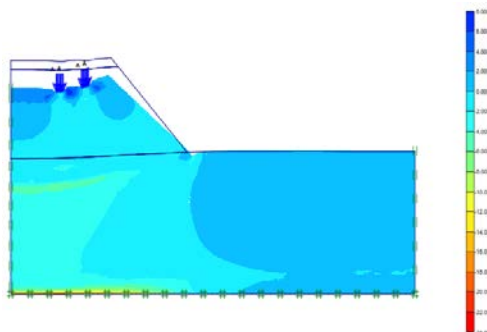
The pavement system has been sustained traffic load in expansive natural soil, and the improved lime embankment was calculated by the FEM program. The expansive soil as landfill embankment caused very large settlement, and the effect of swelling pressure in tensile strain cause a

crack. Improved lime soil of embankment could change tensile strain to compressive strain avoid a crack in pavement structure and decrease total displacement.



Vertical strains (Eps-yy)
Extreme Eps-yy -33.99%

Fig.7 vertical strain output of natural soil embankment



Vertical strains (Eps-yy)
Extreme Eps-yy -23.43%

Fig.8 Vertical strain output of improving landfill embankment

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