Research Article

Analysis of the Effect of Expansive Soil Against Deformation in Development Projects Cikampek - Palimanan Sta 166 + 650 Toll Road

Asep Setiawan[1]

[1]Department of Civil Engineering, Widyatama University, Indonesia
[1]asep.st@widyatama.ac.id

Article History: Received: 10 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 20 April 2021

Abstract On the pavement of the Cikampek-Palimanan Toll Road, STA 166 + 650, there is predicted deformation due to the influence of the expansive soil underneath. Based on this background, it is necessary to conduct research with the aim of obtaining information on the character and physical properties of the sub grade, so as to determine the type of soil stabilization. From the results of soil identification using the single index method according to Chen, 1988 and Snethen, 1977, if the land at the project site is not replaced (replaced) with land that is not expansive, it will have high swelling potential. The potential for settlement of settlement based on Terzaghi and Peck, namely the amount of reduction of 7.3 cm and the time required for a stable condition or consolidation process occurs for 4.8 months. Force height (total heave) for the original soil conditions is relatively large up to 8.52 cm which causes the pavement of the Cikampek-Palimanan Toll Road to experience deformation.
Keywords: Expansive Soil, Swelling Pontential, Settlement, Deformation

1. Introduction

Damage to road construction such as deformation can cause material losses and casualties of road users if this problem is not resolved quickly. If the cause of the deformation occurs in the subgrade, the characteristics of the sub grade must be known. This can be caused by a decrease in soil shear strength, so it is necessary to know the causes of the decrease in strength and sub-grade characteristics, both on vehicle loads and regional influences in the form of drainage and rainfall.

On the Cikampek-Palimanan Toll Road STA 166 + 650 there was damage in the form of deformation on the road pavement. This is predicted due to the influence of the expansionary soil underneath.

Based on this background, it is necessary to conduct research with the aim of obtaining information on the character and physical properties of the sub-grade soil, so as to determine the type of soil stabilization.

2. Literature Review

2.1 Swelling Soil

Swelling soil has a large swelling and shrinkage character, expands in wet conditions and shrinks when dry. In dealing with swelling soils, it is necessary to take into account the strength degradation due to changes in water content. The amount of swelling and shrinkage on the ground is not evenly distributed from one point to another, causing a difference in ground level (differential movement) which can cause losses.can cause losses.

2.2 Measurement and Prediction

2.2.1 Swelling Potential

Swelling potential is defined as the magnitude of the vertical expansion of the soil sample on the oedometer (steel ring), under a vertical load of 1 psi (6.9 t / m^2) and given access to water at the bottom of the soil sample [1].

Thus the relationship can be formulated.

$$\frac{\Delta H}{H_0} = \varepsilon_z$$

Where:

ΔH : change in sample height / sample thickness
H_0 : initial sample height / original sample thickness
ε_z : strain in the vertical direction

2.2.2 Swelling Pressure

Swelling pressure is defined as the stress required to hold the soil in the oedometer so that a volume change does not occur [2].

The amount of stress to withstand the swelling can be calculated by the equation:

$$(P_T)_{\Delta V=0} = \sigma_0 + \Delta\sigma + P_s$$

$(P_T)_{\Delta V=0}$ ranged 2 – 3 T/m^2 (low)

and 150 – 200 T/m^2 (high)

Where:

σ_0 : initial stress

P_s : change / increase in stress to resist swelling

2.2.3 Degree Of Swelling

The effect of the degree of saturation on volume changes (Chen 1988) is shown in Table 1.

Table 1. Degree of Saturation Against Volume Change

Degree of Saturation (Sr) %	Volume Changes (%)
50	0.5
60	1.75
70	3.1
80	4.5
90	5.9
100	7.5

2.2.4 Prediction Swelling

To predict the level of swelling can be done using empirical equations or laboratory data [3,5].

The empirical equation used to predict swelling is:

1) Komornik and David (1969), equations based on statistical data

$$\log (P_T)_{\Delta V=0} = 2.132 + 0.0208\, L_L + 0.00065\, \gamma_d - 0.00269\, W_i$$

$\log(P_T)_{\Delta V=0}$:swelling pressure when the volume changes: 0

Where:

γ_d : dry density (kg/m^3)

W_i : initial water content (%)

2) Vijayvergia and Ghazaly (1973) equations based on the surface heave size(free swell)

$\Delta S_F = 0.0033\, Z\, S_W$ (free)

Where:

ΔS_F : free surface heave

z : the depth of the active zone

2.3 Total Heave

The amount of surface heave on the foundation or structure can be calculated by the following equation:

$$\Delta S = \sum_{i=1}^{n} [S_{Wi}\,\%] \frac{\Delta H_i}{100}$$

Where:

S_{Wi} % : swelling for each layer under the surcharge load $\sigma_0 + \Delta\sigma$

ΔH_i : layer thickness i

2.4 Total Settlement Analysis (ΔH)

Settlement occurs when soil material receives a load on it.

$$(\Delta H) = \frac{C_c}{1+e_0} \cdot H \cdot \log \left(\frac{\sigma'_0 + \Delta\sigma_v'}{\sigma'_{v0}} \right)$$

Settlement (ΔH) can also be calculated by the equation:

$\Delta H = m_v\, \Delta\sigma_v'\, H$

Where:
ΔH : Settlement
Cc : Compression Index
Cv : Index of expansion
eo : Initial pore number
pc : Preconsolidation pressure
mv : Koef. soil volume compression
$\Delta\sigma v'$: Increase in load due to external loads
$\sigma v'$: Effective soil overburden pressure

2.5 Compression Index And Consolidation Index

1) Compression Index (C_c)

Index compression according to Azzouz, 1976:

a. Non-organic soils, silt, loam and silty loam

$C_c = 0.3(e_0 - 0.27)$

b. Organic soils, peat, loam and organic clays:

$C_c = 0.0115w_n$

Where:
w_n : natural / field moisture content

2) Consolidation Coefficient

Cv for soil types with IP > 25 has Cv: 0.1 - 1 m^2 / year ≈ Pressure index or compression index.
Terzaghi and Peck, 1976 proposed:
$C_v = 0.009(w_L - 10\%)$
The value of Cv varies, depending on the type and condition of the soil in the field

2.6 Level of Consolidation

2.6.1 Consolidation Time (t_i)

The duration of the process of a consolidation which results in a settlement is determined by knowing that c_v (Lab), t is taken at the time of the consolidation to reach 50%, so that the time used is t_{50}.

$c_v = k/(m_v\gamma_w) = k(1 + e) / (a_v\gamma_w)$

Then:

$t_i = TH^2/ c_v$

2.6.2 Degree of Consolidation (U)

The degree of consolidation U against the time factor is shown in the equation;

$U = \sqrt{T} / \pi$

Where :
Q : is a time factor
ti : the length of the consolidation process

The relationship between the degree of U consolidation against the time factor is shown in Table 2.

Table 2. Consolidation Percentage Relationship Against Time

U	T
00	0.000
10	0.008
20	0.031
30	0.071
40	0.126
50	0.197
60	0.287
70	0.403
80	0.567
90	0.848
100	∞

2.5.3 Hubungan φ_{ps} terhadap φ_{tr}

2.5.3 φps to φtr

It should be noted that the inner shear angle φ of the triaxial test φtr is 1 - 5 0 less than the inner shear angle of the plane strain test so φps is the principal product of the direct shear test [4].

Lade and Lee (1976) proposed the relationship between φps and φtr, namely:

φps = 1.5φtr - 17 0 for φ > 340

Plan load is obtained from the most critical. The magnification factor of the Ri regulation of the following design load combination needs to be investigated;

a) R_D DL + R_L LL + R_S S + HS SF = 3
b) R_D DL + R_L LL + R_W W + HS SF = 2
c) R_D DL + R_L LL + R_E E + HS SF = 2

DL	dead loads such as construction weight and any permanent burdens.
LL	live loads or all loads that carry irreversible loads but affect construction.
W	wind loads working on open construction.
E	earthquake loads or lateral forces acting on the construction.
HS	hydrostatic loads or all loads caused by water pressure, (+) or (-).
S	snow load acting on the roof, the value is based on regulations.
EP	load due to ground pressure can be vertical or lateral.

Which one ;

Generally SF for temporary loads such as wind and earthquakes is smaller which is not a requirement.

If the planner finds a high load intensity due to a combination of temporary loads then the recommended bearing pressure is not increased arbitrarily by one third or another value without consulting the geotechnical planner.

2.7 Faktor Keamanan Pada Pekerjaan Konstrusi

The SF safety factor that is commonly used in construction work is shown in Table 3.

Table 3. Commonly used SF safety factors

Type of Failure	Foundation Type	**SF**
Sliding	Earthworks, dams, fill etc.	1.2 – 1.6
Sliding	Retaining wall construction	1.5 – 2.0
Sliding	Plaster walls	1.2 – 1.6 1.2 – 1.5
Sliding	Avoid dam, temporary supported excavation.	2 – 3 1.7 – 2.5 1.7 – 2.5
Seepage	Palm foundation, local	3 – 5

3. Research Methodology

This research consists of five groups of work, namely soil sampling, identification of expansive soil, compaction testing with standard compaction (ASTM D-698), testing for development potential (Swelling Potential), testing pressure expansion using the method (free swell pressure test) ASTM D 4546 90 and the lifting power test (Total Heave).

The soil sample used is expansive clay taken at the Cikampek - Palimanan sta 166 + 650 project site, which is one of the samples taken for careful laboratory testing.

Soil properties testing is an early stage research that aims to clarify and identify the soil to be tested. From the results of the tests carried out, the data obtained were analyzed to determine the level of soil expansion using various methods such as the Chen and Skepton methods.

4. Data Analysis Methodology

The collected data are analyzed by empirical method or using analytical formula which is a proof of the hypothesis.

These calculations include:

a. Heave calculation is based on the properties index, degree of saturation and moisture content.
b. Calculation of the maximum shear resistance and soil bearing capacity.
c. Predictive analysis of swelling / expansive soil based on the plasticity index.
d. Thickness of Road Pavement Construction Based on Shear Strength of Soil Permit

To facilitate the research, the stages of research are made which are described in the following flowchart:

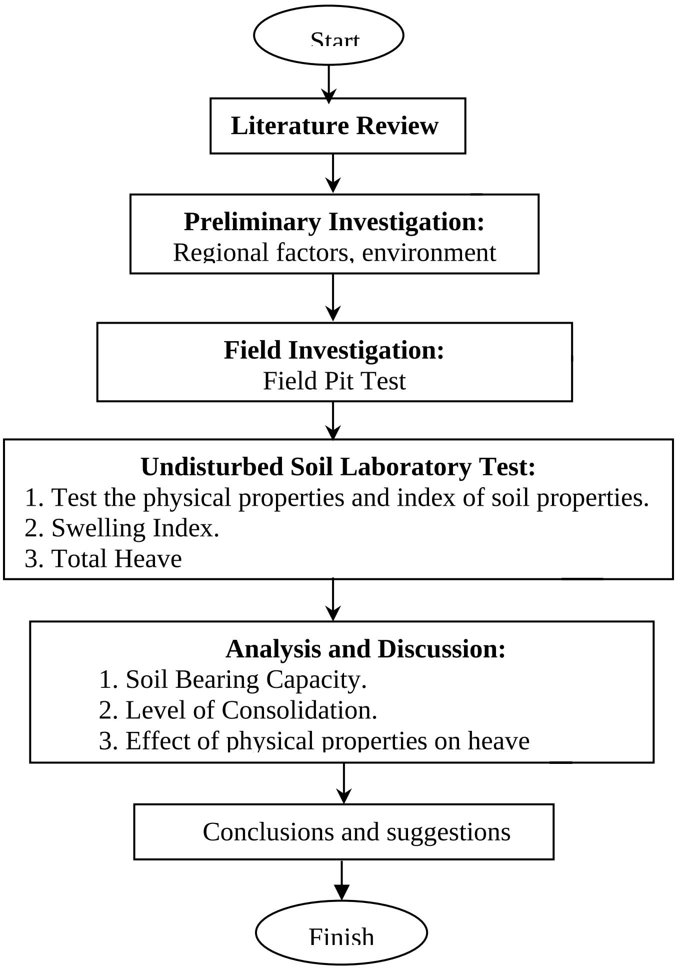

Figure1. Research Flowchart

4. Data Processing and Analysis

4.1 Soil Parameters

Soil tests at the KG-NRC CONSORSIUM Mectant Laboratory Based on the test results in the Mectant Laboratory and existing data on soil parameters, it is shown in Table 4.

Table 4. Parameters and Soil Classification

Parameter Type	Notati on	U nit	Large Parameter

Wet fill weight unit	γ_{wet}	g/cm^3	1.83
Unit dry weight	γ_{dry}	g/cm^3	1.405
Water content	W	%	30
Pore Numbers	E	%	1.27
Specific gravity	G_s	g/cm^3	2.65
Liquid limit	L_l	%	77.50
Plastic Limits	P_l	%	27.36
Plasticity Index	IP	%	50.15
Grain Size Analysis	Sand	%	33.19
	Silt	%	43.20
	Clay	%	23.60
Soil Clasiffication	MH	Soil Clasiffication	
Standard Density	w_{opt}	%	28.25
	$\gamma_{d\,max}$	g/cm^3	1.427
CBR Standard Lab Soaked	95 % $\gamma_{d\,max}$	%	1.41
	100 % $\gamma_{d\,max}$	%	1.87
	S_w	%	4.26 (spec < 1.5)
Swelling	A	%	2.12 (spec < 1.25)

4.2 Soil Stress Calculation

4.2.1 Subgrade Bearing Capacity

<u>Vertical Pressure</u>

a) Effective vertical pressure at a depth of 1.5 m:

<u>FromTable 4.</u>

H = 1.5 m

Wet fill weight unit : 1.83 g/cm^3 ≈ 17.9 kN/ m^3

$\sigma_t = \gamma h = 17.9 \times 1.5 = 26.85$ kN/m^2

u = 0 (groundwater level is below being reviewed)

Groundwater Level is deep from the surface or being reviewed.

Then the stress at a depth of 1.5 m:

$\sigma_t = \gamma\, h = 17.9 \text{ x } 1.5$

$= 26.85$ kN/m^2

so the effective stress σ 'σ' = $\sigma_t - u = 26.85$ kN/m^2

b) Pore water pressure (u),at a depth of 1.5 m :

the groundwater level is below the point analyzed, hw = 0 then; u = γw hw = 9.8 (0) = 0 kN/m^2

c) Total vertical pressure at depth 1.5m :

$\sigma_{vT} = \sigma'_v + u$

= **26.85** kN/m^2 + 0 kN/m^2 = **26.85** kN/m^2

In this case, total teg ≈ teg is effective

Because the groundwater level is below the point analyzed.

4.2.2 Stockpile Land

<u>Landfill Stress</u>

The soil stress of a heap is the addition of stress to the stress (overburden pressure) of the soil before the embankment.

Soil Parameters of Stockpile Material:

Assumption of Stockpile Thickness: 2 m

Soil Type: Red soil (silt)

Unit weight (γ): 18 kN / m

Increase in Stress Δσ

$\Delta\sigma = \gamma$ H

= 18.2 = 36 kN / m^2

Where:

$\Delta\sigma$ *: additional stress due to the embankment*

Stress After Existence of Deposits σ'_v

$\sum \sigma v' = \sigma v' + \Delta\sigma$

= 26.85 + 36 = 62.85 kN/ m^2

Where ;

$\sum\sigma v'$: the amount of effective stress after the embankment

4.3 Settlement Total (ΔH) Analysis

4.3.1 Total Drop (ΔH)

Compression Coefficient

Pressure index or compression index Azzouz, 1976 proposes;

Soil is not organic, silt, loam and loamy silt:

Pori number e: 1.27

$C_c = 0.3(e_0 - 0.27)$

$= 0.3(1.27 - 0.27) = 0.3$

Consolidation Coefficient

Cv for soil types with IP > 25 has Cv: 0.1 - 1 m^2 / year ≈ Pressure index or compression index.

Terzaghi and Peck, 1976 from Skempton's predecessor suggested:

$C_v = 0.009(w_L - 10\%)$

$= 0.009(0{,}775 - 0{,}1) = 6.07510^{-3}$ m^2/day

$\approx 7.03 \times 10^{-8}$ m^2/s

The value of Cv varies, depending on the type and condition of the soil in the field

$$(\Delta H) = \frac{C_c}{1 + e_0} \, . \, H . \log \left(\frac{\sigma_0' + \Delta\sigma_v'}{\sigma'_{v0}} \right)$$

$$(\Delta H) = \frac{0.3}{1 + 1.27} \, . \, 150 . \log \left(\frac{26.85 + 36}{26.85} \right) = 7.3 \text{ cm}$$

So the amount of settlement was 7.3 cm.

Where:;

ΔH : Settlement

Cc : Compression Index

Cv : Index of expansion

eo : Initial pore number

$\Delta\sigma v'$: Increase in load due to external loads

$\sigma v'$: Effective soil overburden pressure

4.4 Consolidation Level

4.4.1 Waktu Consolidasi (t_i)

The duration of the process of a consolidation which results in a settlement is determined by knowing that cv (Lab), t is taken at the time of the consolidation to reach 50%, so that the time used is t50.

$c_v = k/(m_v\gamma_w) = k(1 + e) / (a_v\gamma_w)$

$c_v = 6.075 \times 10^{-3}$ m^2/day

Then:

$t_i = TH^2/ c_v = 0.197 \times (1{,}5)^2/ 7.03 \times 10^{-8}$

= 6305121.91 detik ≈ 2.4 month

So the time needed for a stable condition or the completion of the consolidation process so that the settlement stops is 4.8 months.

4.4.2 Degree of Consolidation (U)

$U = \sqrt{T} / \pi$

Where :

Q : is a time factor

t_i : the length of the consolidation process

The relationship between the degree of consolidation U against the time factor is shown in Table 5.

Table 5. Consolidation Percentage Relationship Against Time

U	T
00	0.000
10	0.008
20	0.031
30	0.071
40	0.126
50	0.197
60	0.287
70	0.403
80	0.567
90	0.848
100	∞

4.5 Swelling Measurement and Prediction

To find out the potential for swelling of the soil, of course we refer to several criteria and formulas regarding the swelling:

<u>Classification of Expansive Soils</u>

a. The classification of expansive soils based on liquid limit, plasticity index and insitu suction (Snethen criteria 1977);

Table 6. Criteria for Snethen 1977 expansive soil based on LL, IP and Insitu Suction.

LL (%)	IP (%)	Potensial Swell (%)	Swell Potential Classification
> 60	> 35	> 1 5	High
50 – 60	25 – 35	0.5 – 1.5	General
< 50	< 25	< 0.5	Low

b. Expansive soil classification based on the plasticity index (Chen's criteria, 1988)

Tabel 7. Chen 1988 criteria for expansive soil by IP (%)

IP (%)	Potensial Swell (%)
0 – 15	Low
10 – 35	Moderate
20 – 55	High
> 55	Very high

c. Effect of degree of saturation (Sr) on volume change (%) (Chen 1988)

Table 8. Effect of degree of saturation on volume changes (%)

Degree of Saturation (Sr) %	Change in Volume (%)
50	0.5
60	1.75
70	3.1
80	4.5
90	5.9
100	7.5

d. Measurement of the swelling potential from the soil
From the results of the soil test are shown in Table 9.

Table 9. Parameters and Soil Classification

Jenis Parameter	Notasi	Satuan	Besar Parameter
Unit berat satuan isi kering	γ_d	kN/m^3	13.77
Kadar air	w	%	30
Batas cair/ liquid limit	L_l	%	77.5
Indeks Plastisitas	IP	%	51
Derajat Kejenuhan	Sr	%	1.75
Swelling	Sw	%	4.26

Refer to Table 5.2 Snethen 1977 criteria
Liquid limit = 94% with IP = 50.15% > 35% having swell potential > 1.5% which is classified as high swelling.

Refer to Table 7 Chen 1988 criteria
IP = 50.15% > 35% including the very high swelling classification.

Refer to Table 5.4 criteria for Chen 1988
Effect of degree of saturation on volume changes (%)
Sr = 63% has a potential change in volume (%) around 1.7%

4.6 Prediction of Expansive Land

a. Komonik and David's (1969) method proposed an empirical formula for predicting swelling, namely:
$\text{Log}\,(P_T)_{\Delta V=0} = 2.132 + 0.0208(L_L) + 0.00065\,\gamma_{dry} - 0.00269\,w_i$
Dari Tabel 4.1;
L_L : 77.5 %
w_i : 30 %
γ_{dry} = 13.77 kN/m^3 ≈ 1405 kg/m^3
Then:
$\text{Log}\,(P_T)_{\Delta V=0} = 2.32 + 0.0208(L_L) + 0.00065\,\gamma_{dry} - 0.00269\,w_i$
$\text{Log}\,(P_T)_{\Delta V=0} = 2.132 + 0.0208(0{,}775) + 0.00065\,(13.77) - 0.00269(0.3) = 2.16$
$(P_T)_{\Delta V=0} = 10^{2.16}$
$= 144.54$ kg/ m^2

b. Total Heave
The amount of total heave on a foundation / structure can be calculated with the formula:

$$\Delta S = \sum_{i=1}^{n} \left(S_{wi}\,\% \right) \frac{\Delta H_i}{100}$$

S_w : 4.26 %
Assume that ΔHi = 2 m and the number of layers n = 3
Thickness per layer of expansive clay ≈ 200 cm, n: 3 layers
Total heave in a foundation / structure

$$\Delta S = \sum_{i=1}^{n} \left(S_{wi}\,\% \right) \frac{\Delta H_i}{100}$$

$$\Delta S \sum_{i=1}^{3} \left(4.26 \right) \frac{200}{100} = 8.52 \text{ cm}$$

Total heave yang terjadi pada suatu konstruksi sebesar **8,52 cm.**
This is what causes damage to the road construction on the land.

5. Conclusions

From the results of the analysis and calculations that have been done, it can be concluded:

a. From the results of land identification using the single index method according to Chen, 1988 and Snethen, 1977, if the land at the Cipal Package 4 toll road project site is not replaced with land that is not expansive, it will have high swelling potential.

b. The expansive soil classification is based on the Aktivity 2.12% of the soil minerals according to (Skempton 1953) including Ca Monmorrilonite.

c. The vertical pressure at a depth of 1.5 is 26.85 kN/m^2 in this case the total stress is the same as the effective stress because the groundwater level is below the point being analyzed, and if it is assumed there is an embankment of 2 m above it, the additional stress is 36 kN/m^2, so the total the effective stress after an accumulation of 62.85 kN/m^2.

d. The potential for settlement of settlement based on Terzaghi and Peck, 1976 from the previous Skempton, is the magnitude of the decrease of 7.3 cm. And the time required for a stable condition or consolidation process to occur for 4.8 months.

e. The total heave height for the original soil conditions is relatively large up to 8.52 cm which causes the pavement of the Cikampek-Palimanan Toll Road to experience deformation.

References

1. Bowles, Joseph E. *Physical And Geotechnical Propertises Of Soils,* Mc Graw – Hill, Inc, 1984
2. Das, Braja M. *Principles Of Geotechnical Engineering*, Hemisphere Publishing Coorporation, 1985.
3. Jabarullah, N. H., Surendar, A., Arun, M., Siddiqi, A. F., & Krasnopevtseva, T. O. (2020). Microstructural Characterization and Unified Reliability Assessment of Aged Solder Joints in a PV Module. IEEE Transactions on Components, Packaging and Manufacturing Technology, 10(6), 1028-1034.
4. Sutarman, Encu. *Mekanika Tanah*, Djatnika CV, 2010.
5. Primorac, J., Uzelac, A., & Bilić, P. (2018). European Union and Challenges of Cultural Policies: Critical Perspectives. An Introduction. Croatian International Relations Review, 24(82), 6-13.