4th International Conference on Rehabilitation and Maintenance in Civil Engineering

METHOD OF REMOVING SECONDARY COMPRESSION ON CLAY USING PRELOADING

Ega Dhianty, S.T.
Prof. Ir. Indrasurya B. Mochtar, M.Sc., Ph.D

Civil Engineering
Faculty of Civil Engineering Environment and Geo Engineering
Institut Teknologi Sepuluh Nopember, Indonesia
2018

Presented by : Ega Dhianty, S.T.

INTRODUCTION

SOIL COMPRESSION

- PRIMARY CONSOLIDATION
- SECONDARY COMPRESSION

Mesri (1973)

$S_s = C\alpha' H \log (t_2/t_1)$, where $C\alpha' = C\alpha / (1+e_p)$

Aliehudien & Mochtar (2009)

$C\alpha' = (0{,}013\ e_0 - 0{,}000062\ LL - 0{,}003)\ P'$

Aliehudien & Mochtar (2009)
The Secondary Compression Index (Cα') is affected by the Effective Consolidation Stress (P'). The greater the Effective Consolidation Stress is, the greater the Secondary Compression Index will become

MATERIALS AND RESEARCH METHODS

Table 1. Soil consistencies for soil that dominant of clay and silt, Mochtar (2012)

Soil Consistencies	Undrained Shear Strength, Cu	
	kPa	ton/m^2
Very Soft	0 – 12.5	0 – 1.25
Soft	12.5 – 25	1.25 – 2.5
Medium	25 – 50	2.5 – 5
Stiff	50 – 100	5.0 – 10
Very Stiff	100 – 200	10 – 20
Hard	> 200	> 20.0

Table 2. Consistencies of tested soil samples

Soil Consistencies	Undrained Shear Strength (Cu) (kPa)
Very Soft	6
Soft	14.8
Medium	36.5

Atterberg Limits Test

↓

Remolded Sample

↓

Volumetric and Gravimetric Test
Oedometer Test

↓

Statistical Analysis with Regression
Calculation of Soil Settlement

RESULTS AND DISCUSSION

❖ Empirical correlation of the secondary compression index as function of void ratio and the effective consolidation stress

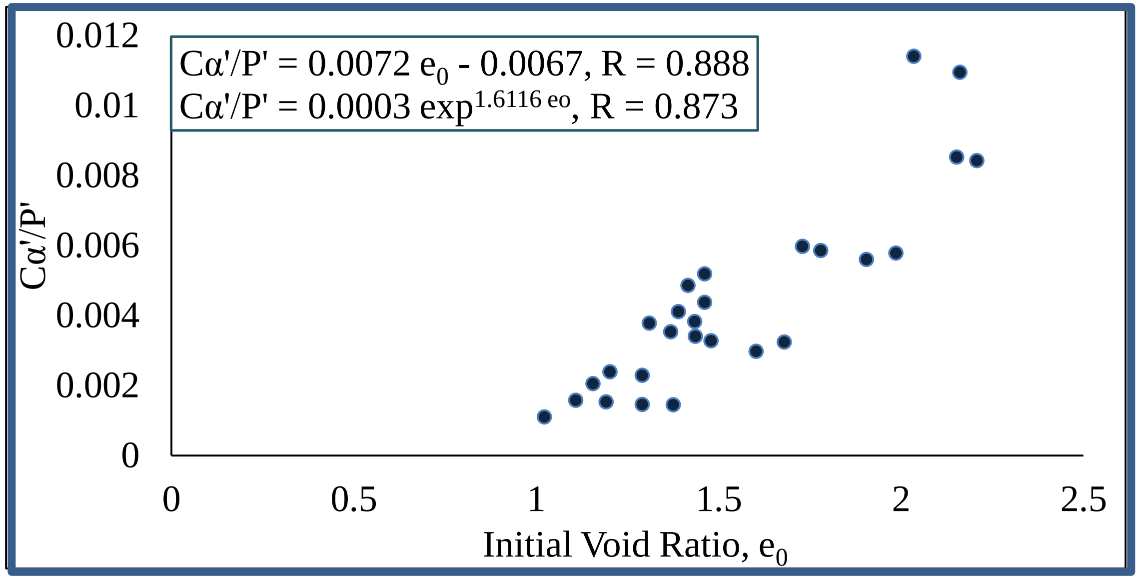


Fig. 1. The relationship between the initial void ratio and Cα'/P'

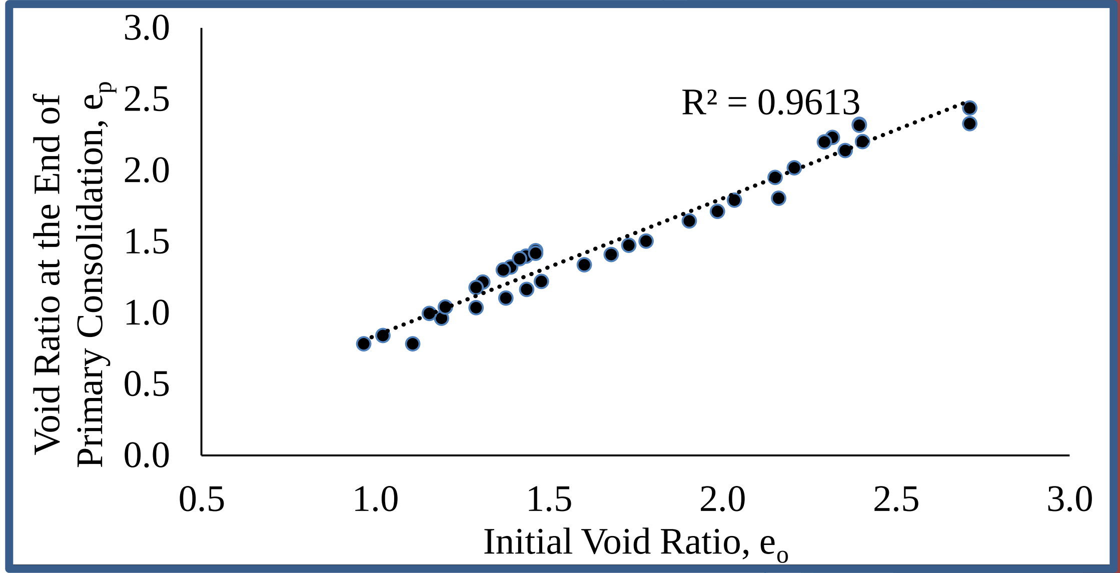


Fig. 3. The relationship between the initial void ratio and the void ratio at the end of primary consolidation

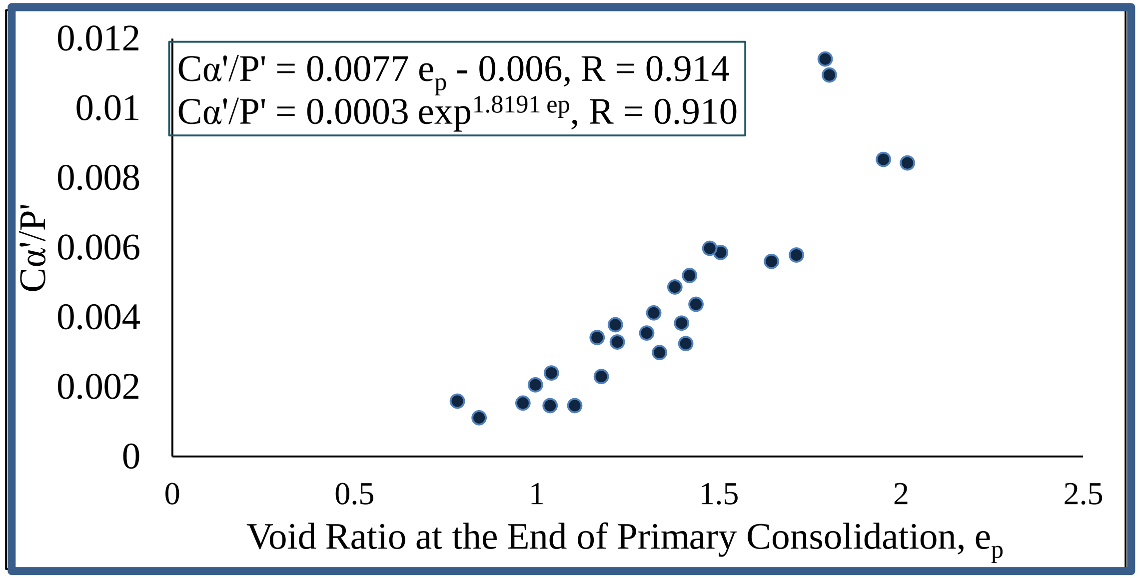


Fig. 2. The relationship between the void ratio at the end of primary consolidation and Cα'/P'

Table 4. The correlation between the secondary compression index (Cα'), the void ratio (e), and the effective consolidation stress (P')

Correlation	R	Regression
$C\alpha' = (0.0072\ e_0 - 0.0067)\ P'$	0.888	Linear **(Eq. 1)**
$C\alpha' = (0.0003\ \exp^{1.6116\ eo})\ P'$	0.873	Exponential
$C\alpha' = (0.0077\ e_p - 0.006)\ P'$	0.914	Linear **(Eq. 2)**
$C\alpha' = (0.0003\ \exp^{1.8191\ ep})\ P'$	0.910	Exponential

❖ Empirical correlation of the secondary compression index as function of void ratio and the effective consolidation stress

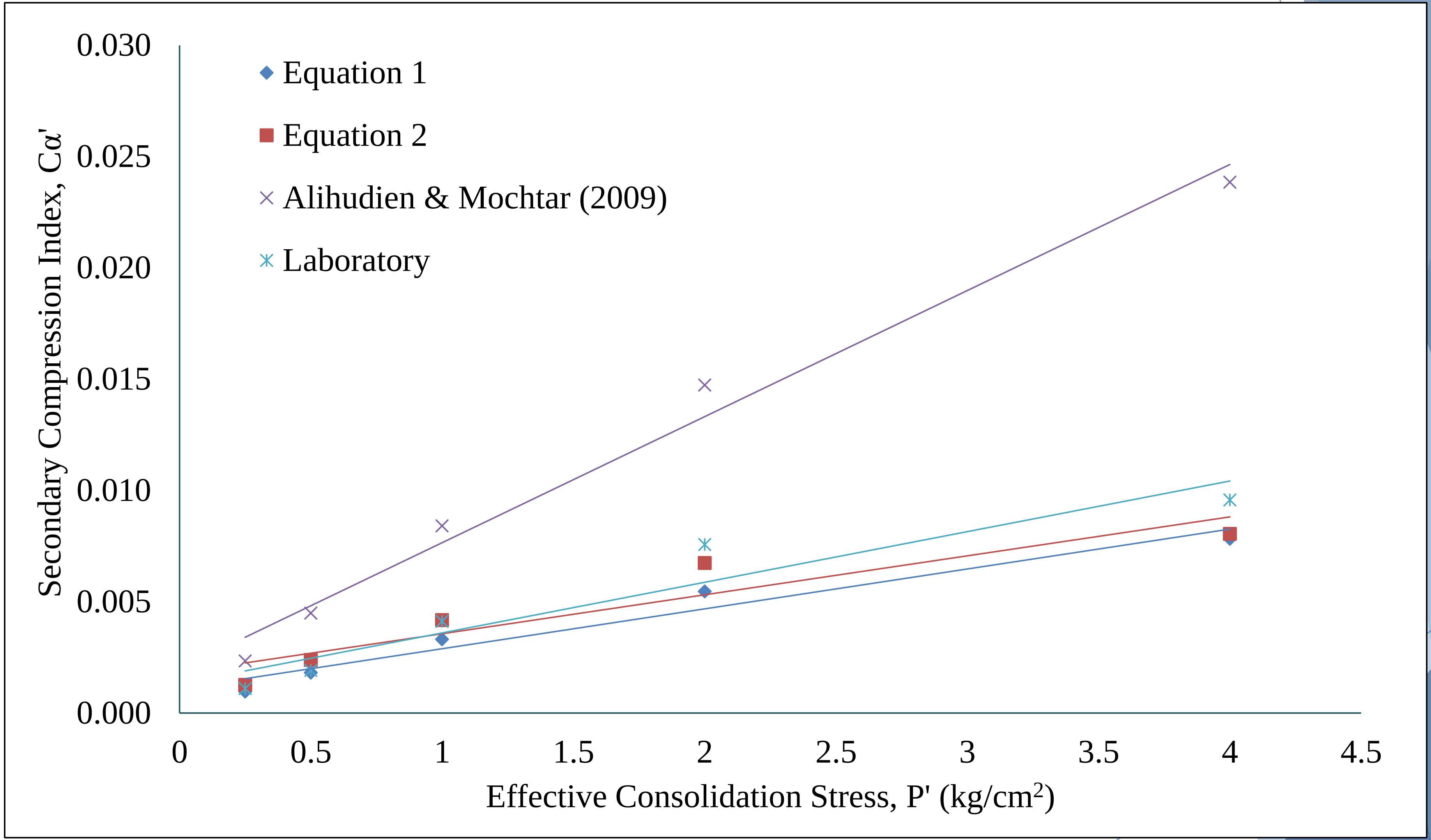
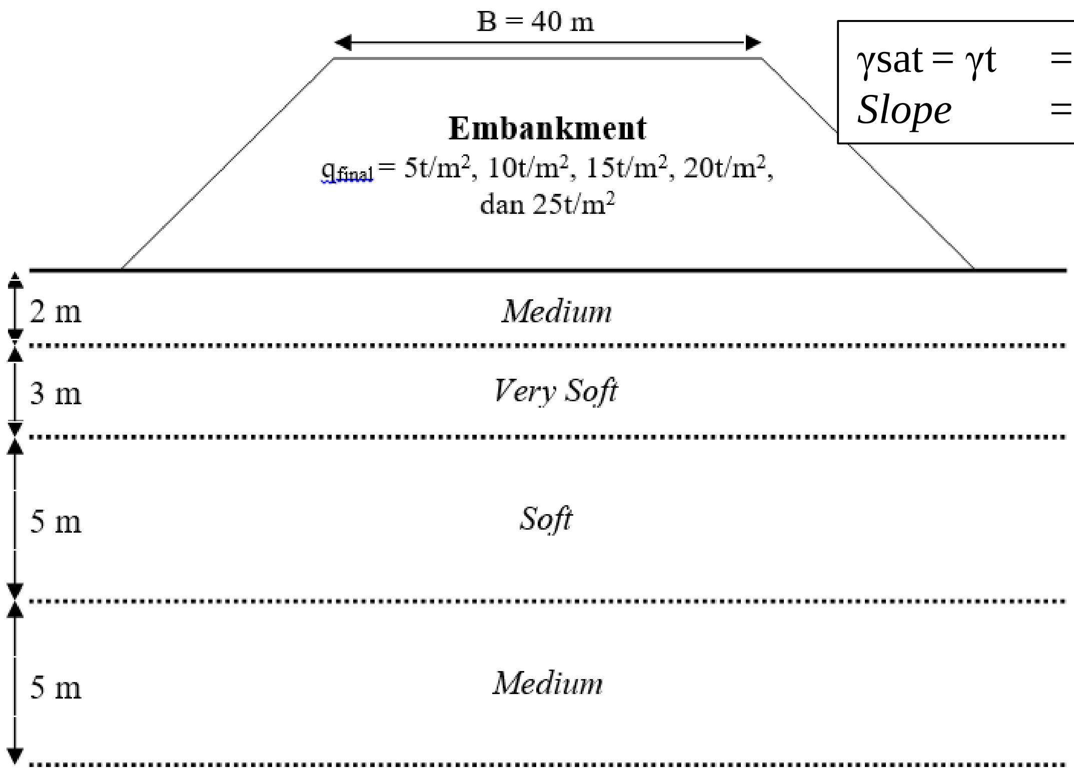


Fig. 4. Comparison of empirical correlation value to data obtained from laboratory

❖ Method of removing secondary compression



$\gamma sat = \gamma t \quad = 1.9\ t/m^3$

Slope $\quad = 1 : 2$

Primary Consolidation - *normally consolidated (NC-Soil)* :

$$Sc = \left[\frac{C_c}{1+e_0}\log\frac{P'_0+\Delta P}{P'_0}\right]H$$

$$H_{initial} = \frac{q_{final} + Sc(\gamma_{embankment} - \gamma'_{embankment})}{\gamma_{embankment}}$$

$$H_{final} = H_{initial} - Sc$$

Secondary Compression (Ss) :

$t_1 = 0.5$ years, $t_2 = 25$ years

$$Ss = C\alpha' \, H \log (t_2/t_1)$$

where :

$C\alpha' = (0{,}0072\ e_0 - 0.0067)\ P'$ or $C\alpha' = (0{,}0077\ e_p - 0.0060)\ P'$

Table 5. Soil Parameters

Depth (m)	H (m)	Consistency	Gs	Unit Weight		Sr (%)	Wc (%)	e	Cu (kPa)	Atterberg's Limit			Consolidation			
				γ_{sat} (t/m^3)	γ_d (t/m^3)					LL (%)	PL (%)	PI (%)	Cc	Cs	Cα	Cv (cm^2/s)
0.0 - 2.0	2	Medium	2.616	1.700	1.063	100	60	1.050	36.5	107.51	42.63	64.88	0.658	0.187	0.0191	0.000181
2.0 - 5.0	3	Very Soft	2.616	1.426	0.705	100	102.25	1.380	6	107.51	42.63	64.88	0.763	0.203	0.0301	0.000108
5.0 - 10.0	5	Soft	2.616	1.483	0.771	100	92.46	1.265	14.8	107.51	42.63	64.88	0.723	0.197	0.0284	0.000159
10.0 - 15.0	5	Medium	2.616	1.700	1.063	100	60	1.050	36.5	107.51	42.63	64.88	0.658	0.187	0.0191	0.000181

❖ Method of removing secondary compression

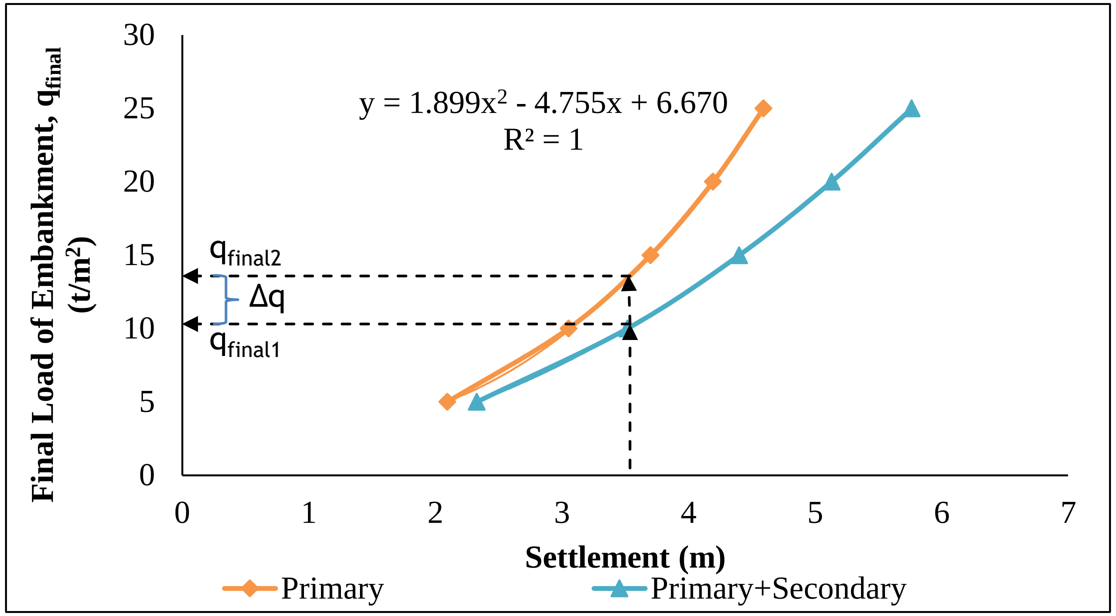


Fig. 5. The relationship between settlement and final load of embankment

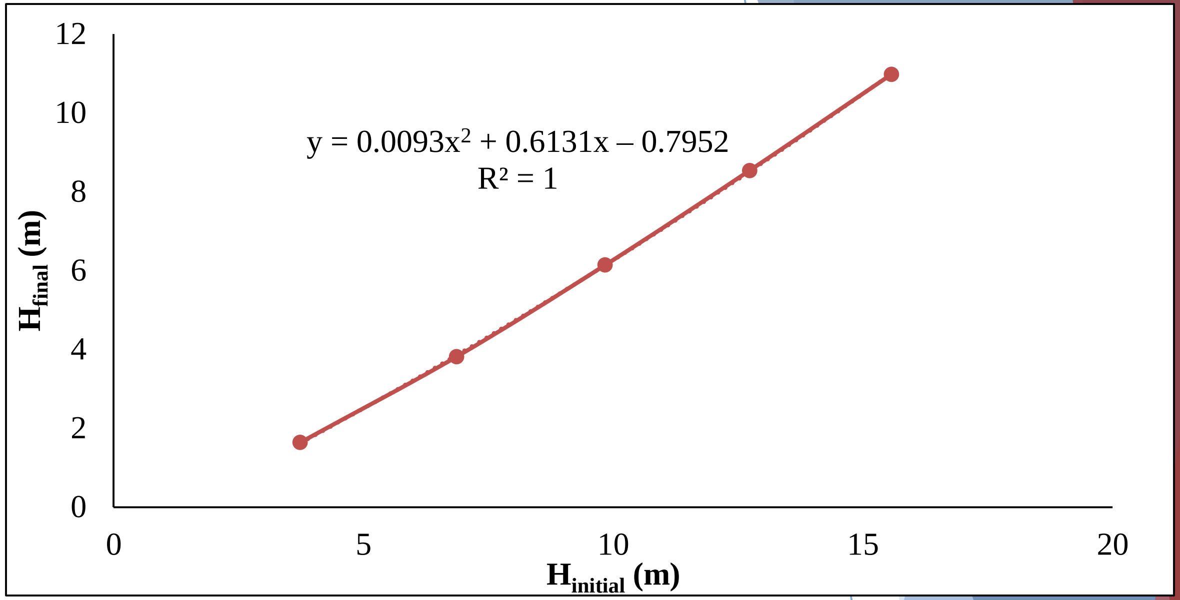


Fig. 7. The relationship between $H_{initial}$ and H_{final}

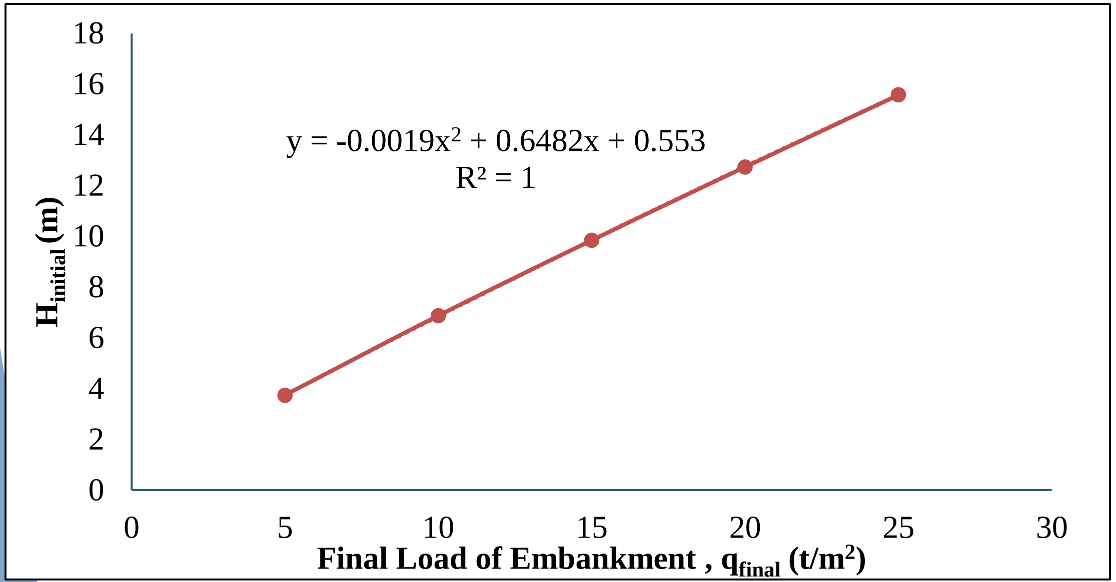


Fig. 6. The relationship between final load of embankment and initial height of embankment

- ❖ Total of primary and secondary compression, S_{total}

  S_{total} = 3.52 m
- ❖ New final load of embankment, $q_{final\ 2}$

  $y = 1.899x^2 - 4.755x + 6.670 = 1.899(3.52)^2 - 4.755(3.52) + 6.670 = 13.46\ t/m^2$
- ❖ Extra load of embankment to remove the secondary compression, Δq

  $q_{final1} = 10\ t/m^2$

  $\Delta q = q_{final\ 2} - q_{final\ 1} = 13.46 - 10\ t/m^2 = 3.46\ t/m^2$
- ❖ Initial height of embankment before primary and secondary compression occurs, $H_{initial(p+s)}$

  $y = -0.0019x^2 + 0.6482x + 0.553 = -0.0019(13.46)^2 + 0.6482(13.46) + 0.553 = 8.93$ m
- ❖ Final height of embankment after primary and secondary compression occurs, $H_{final(p+s)}$

  $y = 0.0093x^2 + 0.6131x - 0.7952 = 0.0093(8.93)^2 + 0.6131(8.93) - 0.7952 = 5.42$ m
- ❖ Final height of embankment in the field after unloaded, $H_{final\text{-}field}$

  $\gamma_{timbunan} = 1.9\ t/m^3$

  $H_{final\text{-}field} = H_{final(p+s)} - \Delta q\ /\ \gamma_{embankment} = 5.42 - 3.46\ /\ 1.9 = 3.6$ m

❖ Method of removing secondary compression

Table 6. The value of $H_{initial}$ dan $H_{final\text{-}field}$

q_{final1}	S_{total}	$q_{final\ 2}$	Δq	$H_{initial(p+s)}$	$H_{final(p+s)}$	$H_{final\text{-}field}$
(t/m²)	(m)	(t/m²)	(t/m²)	(m)	(m)	(m)
5	2.33	5.89	0.89	4.31	2.02	1.55
10	3.52	13.46	3.46	8.93	5.42	3.60
15	4.40	22.53	7.53	14.19	9.78	5.82
20	5.13	32.26	12.26	19.48	14.68	8.23
25	5.76	42.36	17.36	24.60	19.92	10.78

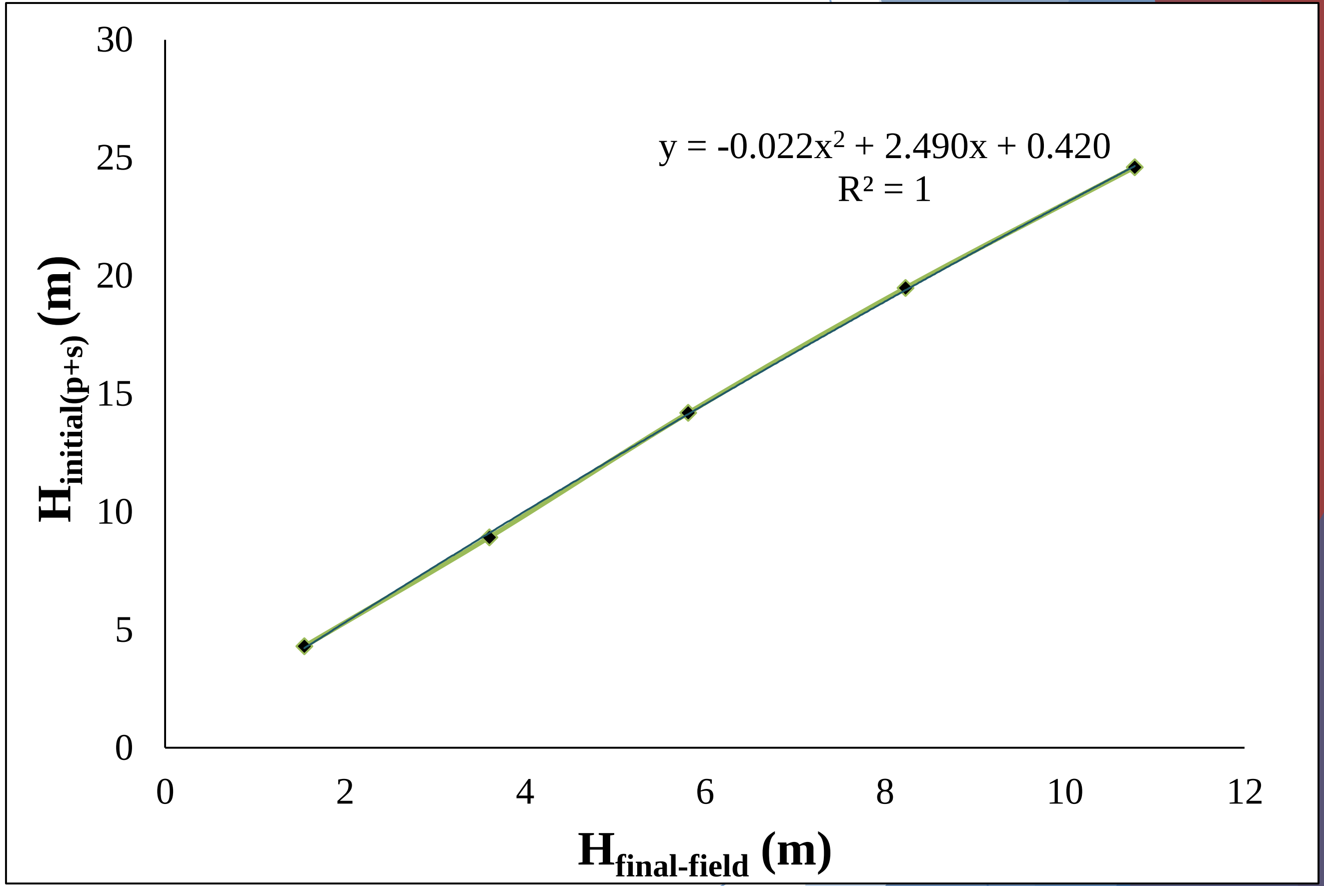


Fig. 8. The relationship between $H_{final\text{-}field}$ and $H_{initial(p+s)}$

❖ CONCLUSION

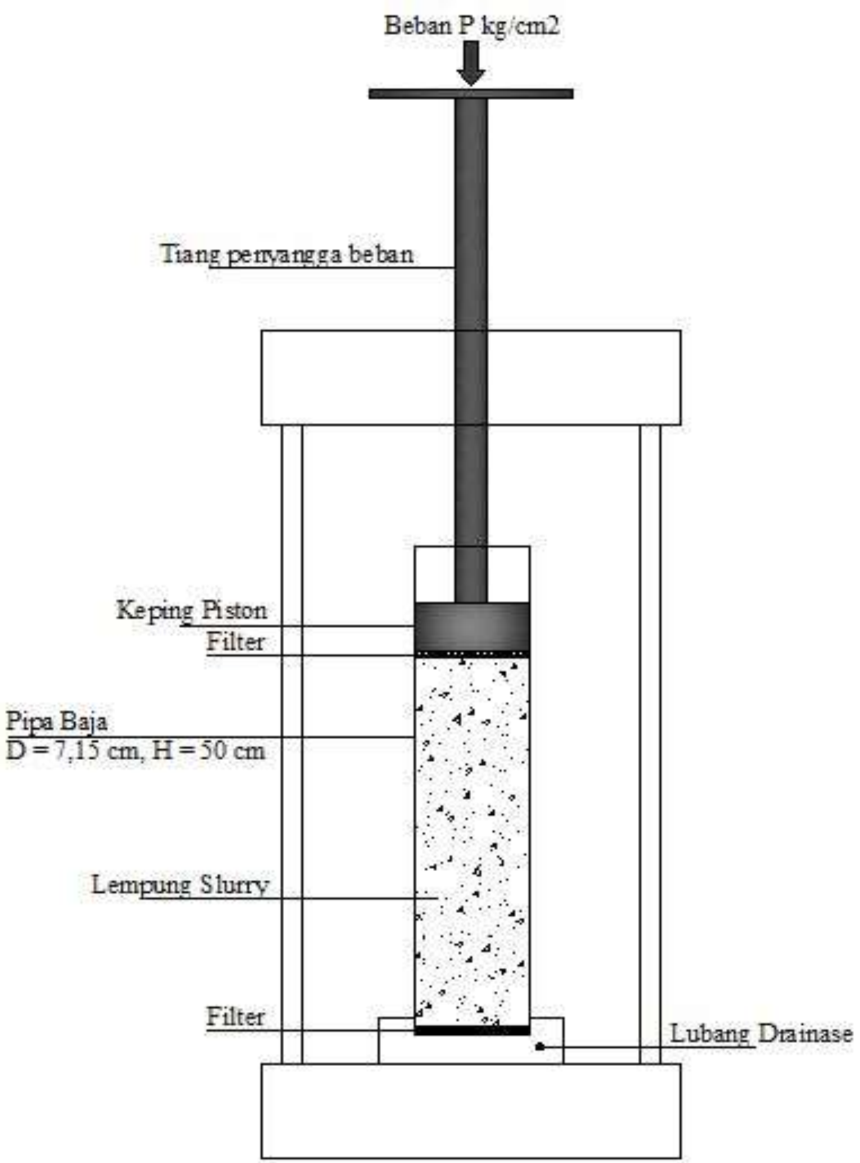
1. Based on laboratory experimental studies and statistical analysis, there are empirical correlations between the secondary compression index (Cα') with the initial void ratio (e_0), the void ratio at the end of primary consolidation (e_p), and the effective consolidation stress (P').
2. Regression between Cα'- e_0 – P' and Cα'- e_p – P' shows a strong correlation between these parameters. Based on the linear regression, the relationship of Cα' – e_0 – P' has the coefficient of determination is R = 0.888, while for the relation Cα'- e_p – P' has R = 0.914. With a fairly high R value of close to 1, this empirical correlation can be used in predicting the secondary compression index. The correlations obtained from this study are as follows:
   $C\alpha' = (0.0072\, e_0 - 0.0067)\, P'$ and $C\alpha' = (0.0077\, e_p - 0.006)\, P'$
   where : Cα' is the secondary compression index, e_0 is the initial void ratio, e_p is the void ratio at the end of primary consolidation, and P' is the effective consolidation stress which is the magnitude of the addition of stress due to the external load (ΔP), P' = ΔP.
3. The value of the secondary compression index (Cα') is influenced by the effective consolidation stress (P'). The greater the effective consolidation stress (P') is, then the greater the secondary compression index (Cα') will become. So that the secondary compression can be removed along with preloading at the time of removal of the primary consolidation. Secondary compression can be removed by giving an extra load (Δq) that causes additional compression to the primary consolidation where the magnitude equals to the expected secondary compression. Then, this Δq could be removed at the end of the primary consolidation. So that after soil improvement with preloading is completed, there is no more settlement caused by primary consolidation and secondary compression. The extra load (Δq) during preloading will make the soil become more compressive such that increases undrained shear strength value (Cu). The increasing value of Cu causes the secondary compression index (Cα') to be smaller. So that the extra load (Δq) at the time of preloading can eliminate the secondary compression at a certain time period.

❖ REFERENCES

1. A. Alihudien, I. B. Mochtar, *Usulan Perumusan Pemampatan Konsolidasi Sekunder untuk Tanah Lempung*, "Pertemuan Ilmiah Tahunan XIII 2009 Himpunan Ahli Teknik Tanah Indonesia" Proceedings, Denpasar Bali, ISBN: 978-979-96668-7-1, (2009).
2. B. M. Das, K. Sobhan, *Principles of Geotechnical Engineering 8th Edition*. SI, Global Engineering: Christopher M. Shortt, **381-389**, (2012).
3. C. C. Ladd, *Settlement Analysis ff Cohesive Soils*, Research Report R71-2. Cambridge, MA: MIT, (1994).
4. D. C. Koutsoftas, R. Foott, L. D. Handfelt, *Geotechnical Investigations Offshore Hong Kong*, J. Geotech. Engng. Div., ASCE 113, No. 2, **87-105**, (1987).
5. E. E. Alonso, A. Gens, A. Lloret, *Precompression Design For Secondary Settlement Reduction*, Geotechnique 50, No. 6, **645-656**, (2000).
6. G. Mesri, *Coeffisient of secondary Compression*, Journal of the Soil Mechanics and Foundations Divisions. Proc. ASCE Vol. 99 No. SM1, pp **123-137**, (1973).
7. G. Mesri, M. A. Ajlouni, T. W. Feng, D. O. K. Lo, *Surcharging of Soft Ground to Reduce Secondary Settlement*, U.S.A, Republic of China, (1973).
8. I. B. Mochtar, *Empirical Parameters for Soft Soil in Situ*, Civil Engineering Department-ITS, (2006) and Revised (2012).
9. I. B. Mochtar, *Teknologi Perbaikan Tanah dan Alternatif Perencanaan pada Tanah Bermasalah (Problematic Soils)*, Civil Engineering Department-ITS, **126**, (2002).
10. J. Chu, B. Indraratna, S. Yan, C. Rujikiatkamjorn, *Practical Considerations For Using Vertical Drains in Soil Improvement Projects*, Proceedings of the Institution of Civil Engineers: Ground Improvement, 167 (3), **173-185**, (2014).
11. K. P. Yu, R. P. Frizzi, *Preloading Organic Soils To Limit Future Settlements. In Vertical And Horizontal Displacements Of Foundations And Embankments*, ASCE Geotechnical Special Publication No. 40, Vol. 1, **476-490**, (1994).

Q and A?

MATERIALS AND RESEARCH METHODS



❖ Soil parameters obtained from laboratory tests

Table 3. Soil parameters

	Very Soft	Soft	Medium
γ_{sat} (g/cm^3)	1.426	1.483	1.700
γ_d (g/cm^3)	0.705	0.771	1.063
e_0	1.380	1.265	1.050
Wc (%)	102.25	92.46	60
Gs	2.616	2.616	2.616
Cu (kPa)	6.0	14.8	36.5
Atterberg Limits			
LL (%)	107.51	107.51	107.51
PL (%)	42.63	42.63	42.63
PI (%)	64.88	64.88	64.88
Consolidation			
Cc	0.763	0.723	0.658
Cs	0.203	0.197	0.187
C_v (cm^2/s)	0.000108	0.000159	0.000181
Cα	0.0301	0.0284	0.0191

❖ Method of removing secondary compression

$C\alpha' = (0.0072\ e_0 - 0.0067)\ P'$ (eq.1)
$C\alpha' = (0.0077\ e_p - 0.006)\ P'$ (eq.2)

The value of Cα' is influenced by the effective consolidation stress (P')

Mesri (1973), Koutsoftas et all (1987), Ladd (1994), Yu & Frizzy (1994)

The secondary compression is significantly reduced when soils are over consolidated to moderate levels, indicating that the use of preload is greater than the final embankment/structural load, this is an effective method of reducing secondary compression

Alonso, Gens, & Lloret (2000)

The secondary compression coefficient (Cα) decreased significantly with an increase in the over consolidation ratio (OCR), so pre-consolidation is an effective method of removing secondary compression

Secondary compression can be removed along with preloading at the time of removal of the primary consolidation. Secondary compression can be removed by giving an extra load (Δq) that causes additional compression to the primary consolidation with the magnitude equals to the expected secondary compression. Then, this Δq could be removed at the end of the primary consolidation. So that after soil improvement with preloading is completed, there is no more settlement caused by primary consolidation and secondary compression.