# ANALYSIS OF CHANGE IN THE AREA OF INUNDATION DUE TO LAND SUBSIDENCE IN SEMARANG (A Case Study: Jl. Ahmad Yani, Jl. Erlangga Tengah, Jl. Sugiyopranoto)

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***Abstract -*** Semarang is located on the north coast of Java island and develops in river flow area which genetically has alluvial materials. The process of precipitation continues until now and as a result a fairly thick layer of clay is founded. The layers of clay and land subsidence are related to each other. Land subsidence causes inundation or locally called rob area becoming increasingly widespread. The process of land subsidence causes a loss for the government of Semarang. The purpose of this study was to analyze the change in the area of inundation due to land subsidence in Semarang, on Ahmad Yani Street, Central Erlangga Street, and Sugiyopranoto Street, and give the best advice for the government to develop the city. Method of analysis used in this study was terzaghi method, GIS software (Geography Information System), and Plaxis software. The results showed that the rates of the land subsidence is getting bigger and the time is getting longer.

***Keywords***: Land Subsidence, Terzaghi, Geography Information System, Plaxis

## 1. Introduction

The growth of people and development in Indonesia is very rapid, particularly in Semarang city which has 1.765.396 people with an area of 373.4 km$^2$ and 17 sub-districts (Department of Population and Civil Registration of Semarang, 2017).

North Semarang is formed by alluvial swamp sediment, the process of land subsidence that occurred in North Semarang causes harm to the Semarang city government, society, and the local industry. This study provides problem limitations, they are:

1) The research location is located in South Semarang Sub-district on Ahmad Yani Street, Central Erlangga Street, and Sugiyopranoto Street.
2) Measuring land subsidence based solely on land consolidation.
3) Analyzing land subsidence on the alluvial plain in South Semarang Sub-district in 2017 until it reaches T90%.
4) Identifying changes in the area of inundation due to land subsidence on alluvial plain in South Semarang Sub-district in 2017 to reach T90%.

## 2. Research Methodology

Experimental research was used on this case study in South Semarang. The research area was generally consisted of alluvium rock system which was still young and having several hundred years age so that keeps it in experiencing compression. The study was conducted in the middle of 2017. The soil sample used the analyzed primary data to determine the dominant soil layer in the research location. The number of samples are 3 points with varying depth between 25-30m.

The research was conducted in one of the sub-districts of Semarang, that was South Semarang sub-district on Ahmad Yani Street, Central Erlangga Street, and Sugiyopranoto Street. The research locations were in the form of settlement, industrial complex, trade and service center.

- Analysis Method

**1) Laboratory Analysis**

1.1 Filter Analysis Test
1.2 Water content (W)
1.3 Specific Gravity Test ($G_s$)
1.4 Liquid Limit Test (LL) and Void Ratio ($e_o$)
1.5 Consolidation Test (Cv) and Compression Index (Cc)

**2) Analysis and Research Steps**

The analysis test of alluvial sediment subsidence was obtained from laboratory calculation based on samples and primary data. The calculation was done in two ways, there were 1D Terzaghi approach and PLAXIS software usage. The results of PLAXIS software usage were the magnitude and the time of land subsidence with different loading and soil mechanical state. The results of manual calculations (Terzaghi) and Plaxis were compared to obtain the final result of the magnitude and the time of land subsidence as well as the subsidence tendency.

The changes in the area of inundation were determined using the GIS (*Geographic Information System*) software, the changes analysis in the area of inundation were obtained by assigning value categories on four variables, there were the soil load, the decrease of the groundwater surface, the thickness of alluvial sediment, and the soil-bearing capacity. The four variables were overlaid and resulting on prediction map of land subsidence. The prediction map of land subsidence was overlaid with topography map (secondary data) and the result was a prediction map of change in the area of inundation.

**3) Terzaghi Analysis**

The magnitude and time of inundation calculation used 1D Terzaghi manual approach as follows:

3.1 Loading each layer (loking for Δσ).

Thickness of pile = h m
γ pile = γ t/m$^3$
$\Delta\sigma = \gamma \times h$ (1)

3.2 Calculation of initial effective strain (finding σ') of each layer

Depth 0m – 1m = $(1\text{-}0)\gamma'/2$(2)

3.3 Calculation of the final effective strain (finding σ1)

Depth 0m - 1m
$\sigma 1 = \sigma' + \Delta\sigma$ (3)

3.4 Looking for subsidence degression of each layer (ΔS)

$\Delta S = \Delta h \,.\, \frac{Cc}{1+eo} \log \frac{\sigma 1}{\sigma} 90\%$ (4)

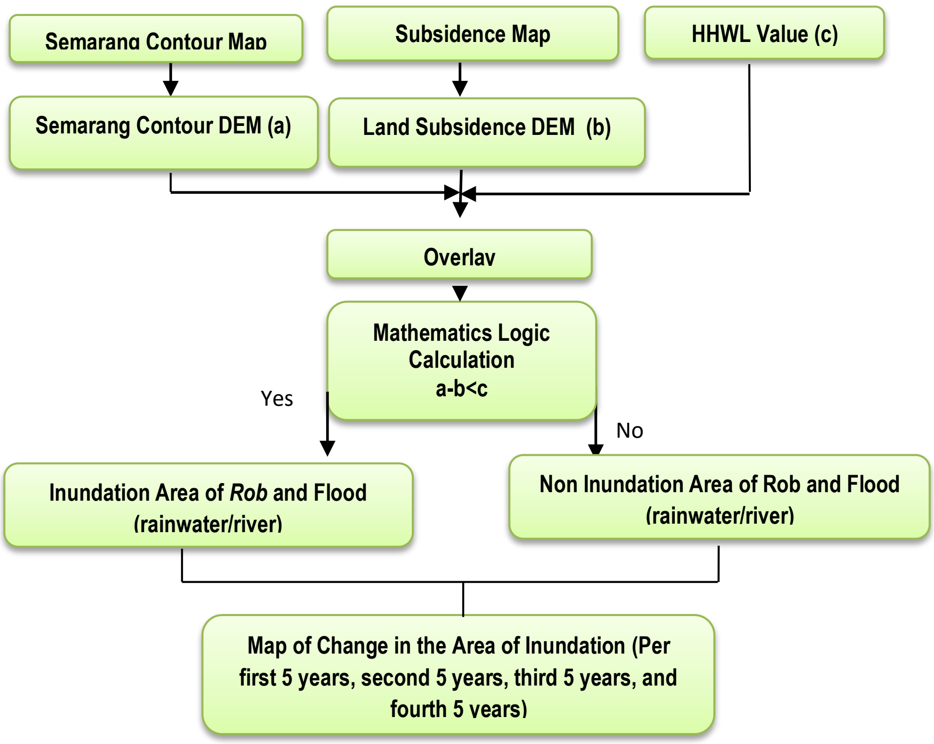
3.5 Looking for land subsidence time on Ahmad Yani Street

$t = \frac{Tv\,.H2}{Cv}$ (5)

4) **PLAXIS Software Analysis**

- Setting dimensions to create a soil profile.
- Creating a soil transverse profile at the drill site based on laboratory analysis result.
- Making soil identification by entering parameters according to the soil type.
- After finishing on making the soil parameters, create a name for the soil type that will be put in the plaxis modeling.
- All layers are filled, then put loading on the top soil layer according to the soil parameters.
- Next look at the initial water pressure state.
- Then enter the *stage construction* parameters.
- Wait for the running result and the final result of degression magnitude will appear

5) **GIS Analysis**




**Picture 1.2.** Overlay Technique Scheme for Inundation Hypotheses

- Use contour map, the contour map is obtained from *Digital ElevationModel* (DEM)
- Use subsidence map, the subsidence map is obtained from overlay result between Terzaghi and Plaxis software.
- Use *Highest High Water Level* (HHWL) value, it is the highest tide of sea water and the elevation of the river that occur over a period of time.
- Then from the above three variables, it can be found out automatically with GIS to determine the area of inundation.

- When the contour line is lower from HHWL, it signs that the area is inundated. When the contour line is higher than HHWL, it signs that the area is not inundated

## 3. Result and Discussion

- Soil Mechanical State

On the research location from secondary data there were 3 drill points spread on the alluvial plain with the depth of drill location was about 25 m, as seen on Picture 4.1. In the needs of prediction on calculating the subsidence's magnitude and time of soil mechanics data, it needs further research. A detailed picture of soil characteristics and mechanics was explained on one point in Ahmad Yani Street (drill point number 1)

- Terzaghi Calculation Example

The calculation example of subsidence's magnitude and time using Terzaghi method in Ahmad Yani Street is as follows :

1. Loading calculation (finding $\Delta\sigma$) each layer

   Thickness of pile (h) = 0,5 meter
   ($\gamma$) pile = 1,8 t/m$^3$
   $\Delta\sigma$ = $\gamma$ x h
   = 1,8 x 0,5
   = 0,9 t/m$^2$
   Thickness of pile (h) = 1 meter
   ($\gamma$) pile = 1,8 t/m$^3$
   $\Delta\sigma$ = $\gamma$ x h
   = 1,8 x 1
   = 1,8 t/m$^2$

2. Calculation of initial effective strain (finding σ') of each layer

   Depth 0 m – 0,5 m $= \left(0{,}5\times\frac{\gamma}{2}\right) = \left(0{,}5\times\frac{1{,}8}{2}\right) = 0{,}45$ t/m$^2$

3. Calculation of final effective strain ($\sigma_1$)

   Depth 0 m – 0,5 m = 0,45 + 0,9 = 1,35 t/m$^2$

4. Calculation of Looking for subsidence degression of each layer ($\Delta S$)

$$\Delta S = \Delta h \times \frac{Cc}{(1+e_o)} \log\left(\frac{\sigma_1}{\sigma'}\right) \times 90\%$$

Where :

| | | | | | |
|---|---|---|---|---|---|
| $\Delta S$ | : | The amount of subsidence | $e_o$ | : | Void Ratio |
| $\Delta h$ | : | Reviewed soil layer | σ' | : | Final effective strain |
| Cc | : | Compression index | σ1 | : | Initial effective strain |

Depth 0 m – 0,5 m $= \frac{0{,}332}{(1+1{,}34)} \log\left(\frac{1{,}345}{0{,}45}\right) 90\% = 0{,}06$ m

$\sum = 0{,}199$ m = 19,9 cm

5. Calculation subsidence time (t)

$$t = \frac{Tv \times H^2}{Cv}$$

Where:

t : Degression time — H : Thickness of soil layer

Tv : *Time factor* — Cv : Consolidation coefficient

Known the result from laboratory was:

Tv : (table)

Cv : 0,00702 $cm^2$/dt

H : 1300 cm

$$t_0 = \frac{Tv \times H^2}{C_v} = \frac{0 \times 1300^2}{0,00702} = 0 \text{ year}$$

$$t_{10} = \frac{Tv \times H^2}{C_v} = \frac{0,008 \times 1300^2}{0,00702} = 1925925,926 \text{ seconds} = 0,061 \text{ year}$$

Using the same way, the calculation of subsidence magnitude and timing can be seen on Table 1.

**Table 1. Prediction of the subsidence magnitude and timing reaching T90% with 1D approach from Terzaghi**

| Drill Point Number | Location | Subsidence Magnitude (cm) | Subsidence Timing (Year) |
|---|---|---|---|
| 1 | Ahmad Yani Street | 19,9 | 6,47 |
| 2 | Central Erlangga Street | 8,4 | 4,63 |
| 3 | Sugiyopranoto Street | 10,8 | 19,83 |

*Source: Analysis and Calculation Result 2017*

Map prediction of land subsidence was made from distribution of point drill when subsidence happened in the research location. Interpolation was done using ArcGIS software with IDW (Inverse Distance Weighted) method. From the result, the land subsidence could be calculated.

Based on soil mechanical analysis result on drill points, there were 5 interval classes of land subsidence depth as seen on Table 2.

Level I shows the smallest subsidence depth level, weheras level V shows the biggest subsidence depth level.

**Table 2. The Depth Level of Land Subsidience Reaching T90% with 1D approach from Terzaghi**

| Depth Level | Subsidience Depth Value | Location |
|---|---|---|
| Level I | 0-20cm | Ahmad Yani Street, Central Erlangga Street, Sugiyopranoto Street |
| Level II | 21-40cm | - |
| Level III | 41-60cm | - |
| Level IV | 61-80cm | - |
| Level V | >80cm | - |

*Source: Analysis and Calculation Result 2017*

- Analysis using Plaxis software

The next calculation analysis was using Plaxis Software 8.2. The result of the calculation using Terzaghi method could be compared to the one using Plaxis software 8.2. The entered soil parameter in Plaxis 8.2 model using data input, consited of : E (Modulus Young), poisson's ratio, cohession, and shear strength.

The final result using software PLAXIS in Ahmad Yani Street as follows:

**Table 3. Prediction of the Alluvial Plain Degression Magnitude with Plaxis Software**

| Drill Point Number | Location | Degression Time (Year) | Degression Magnitude (cm) |
|---|---|---|---|
| 1. | Ahmad Yani Street | 6,47 | 0,2 |
| 2. | Center Erlangga Street | 4,63 | 0,09 |
| 3. | Sugiyopranoto Street | 19,83 | 0,11 |

*Source: Analysis and Calculation Result 2017*

Plaxis Software 8.2 modelling gave degression result which was bigger than Terzaghi, because Terzaghi method did not use parameter like Modulus Young and Poisson Ratio so it influenced on the gained result. Plaxis calculation was more accurate since it counted the degression from not only one dimension.

- Land Subsidence Prediction per year (2018, 2019, 2020, 2021, and 2022)

There was a calculation for Ahmad Yani Street using Plaxis Software 8.2 as stated as follows :

$$a = \frac{\Delta S}{T90} = \frac{20,5}{6,47} = 3,16$$

so,

$$b_{2017} = a.x = 3,16.1 = 3,16$$
$$b_{2018} = a.x = 3,16 . 2 = 6,32$$
$$b_{2019} = a.x = 3,16 . 3 = 9,48$$
$$b_{2020} = a.x = 3,16 . 4 = 12,64$$
$$b_{2021} = a.x = 3,16 . 5 = 15,8$$

**Table 4. Prediction of the Alluvial Plain Degression Magnitude Per One Year Calculation using Terzaghi Method**

| Drill Points Number | Location | Degression Magnitude Per Year (cm) | 2018 (cm) | 2019 (cm) | 2020 (cm) | 2021 (cm) | 2022 (cm) |
|---|---|---|---|---|---|---|---|
| 1 | Ahmad Yani Street | 3,07 | 3,07 | 6,14 | 9,21 | 12,28 | 15,35 |
| 2 | Central Erlangga Street | 1,81 | 1,81 | 3,62 | 5,43 | 7,24 | 9,05 |
| 3 | Sugiyopranoto Stree | 0,54 | 0,54 | 1,08 | 1,62 | 2,16 | 2,7 |

**Table 5. Prediction of the Alluvial Plain Degression Magnitude Per One Year Calculation using Plaxis Software 8.2**

| Drill Points Number | Location | Degression Magnitude Per Year (cm) | 2018 (cm) | 2019 (cm) | 2020 (cm) | 2021 (cm) | 2022 (cm) |
|---|---|---|---|---|---|---|---|
| 1 | Ahmad Yani Street | 3,16 | 3,16 | 6,32 | 9,48 | 12,64 | 15,8 |
| 2 | Central Erlangga Street | 1,94 | 1,94 | 3,88 | 5,82 | 7,76 | 9,7 |
| 3 | Sugiyopranoto Stree | 0,55 | 0,55 | 1,1 | 1,65 | 2,2 | 2,75 |

- Subsidence Prediction Per Five Years Using Terzaghi Method
  Based on the above prediction, it was known that degression magnitude on Ahmad Yani street was 19.9 cm with degression time 6.47 years, then it could be calculated and concluded that the degresion result was 3.07 per year. Therefore degression magnitude on 2023 based on degression assumption per year was 15.35 cm. The next 2028, there will be degression of 30.7 cm, the next 2033 the degression will reach 46.05 cm, and on the following years the degression will occur continously. On the last 2043, the highest result was gained where it had reached T 90% where the degression was 19.9 cm.

**Table 1.6 Prediction of the Alluvial Plain Degression Magnitude on the Per Five Years Calculation Using Terzaghi Method**

| Drill Point Number | Location | 2018 (cm) | 2022 (cm) | 2027 (cm) | 2032 (cm) | 2037 (cm) | 2042 (cm) |
|---|---|---|---|---|---|---|---|
| 1 | Ahmad Yani Street | 3,07 | 15,35 | 19,9 | - | - | - |
| 2 | Central Erlangga Street | 1,81 | 8,4 | - | - | - | - |
| 3 | Sugiyopranoto Stree | 0,54 | 2,7 | 5,4 | 8,1 | 10,8 | - |

On the Central Erlangga Street the degression magnitude at T 90% was 8.4 cm. If it was calculated 1.81 x 25 (2018 up to 2042) it had reached 45.25 cm. Therefore that calculation was no longer valid at T 90% formula since on the initial calculation, degression time on the area was 4.63 year meaning that on the 25$^{th}$ year (2042) the degression had reached T 90%. As well as Sugiyopranoto Street. It could be concluded that this area had no subsidence value on the next 5 years.

- Subsidence Prediction Per Five Years using PLAXIS 8.2
  The Ahmad Yani Street experienced degression T 90% of 20.5 cm where it was calculated that 3.16 x 25 (2018 up to 2042), the degression reached 79 cm. The land degression time result of Ahmad Yani Street was 6.47 years meaning that on 2025, the degression had reached T 90%. The calculation results from plaxis software and Terzaghi showed the same result.

**Table 1.7. Prediction of the Alluvial Plain Degression Magnitude on the Per Five Years Calculation Using Plaxis Software 8.2**

| Drill Points Number | Location | 2018 (cm) | 2022 (cm) | 2027 (cm) | 2032 (cm) | 2037 (cm) | 2042 (cm) |
|---|---|---|---|---|---|---|---|
| 1 | Ahmad Yani Street | 3,16 | 15,8 | 20,5 | - | - | - |
| 2 | Central Erlangga Street | 1,94 | 9 | - | - | - | - |
| 3 | Sugiyopranoto Stree | 0,55 | 2,75 | 5,5 | 8,25 | 11 | - |

## 4. Conclusion

1. Land subsidence which happened in South Semarang Sub-districts is influenced by the physics characteristics and soil mechanics as well as loading on the surface.
2. Land subsidence values which happened on Ahmad Yani Street, Central Erlangga Street, and Sugiyopranoto Street were not too big.

## Literatur


Abidin ,HZ, 2006. *Studi Subsiden Di Wilayah Semarang Dengan Metode InSAR dan GPS*. Riset Unggulan Terpadu XII. Bandung.

Abidin, HZ, H.Andreas, I. Ggumilar, M. Gamal, T.P. Sidiq, Y. Fukuda, D. Murdohardono, Supriyadi, 2010. *Geodetic Monitoring of Land Subsidence in Indonesi (Semarang)*. Laporan Penelitian Riset Unggulan Terpadu. Bandung.

Andre Tupang, https://sci-geoteknik.blogspot.co.id. Diakses pada 20 Agustus 2017.

Bambang, Darno Y, dkk, 2013. *Analisa Geospasial Penyebab Penurunan Muka Tanah Di Kota Semarang*. Publikasi Ilmiah Universitas Wahid Hayim. Semarang

Brinkgreve, R. B. J. and Vermeer, P. A., *Plaxis Version 8.2*. Plaxis B.V. University of Stugart, A.A. Rotterdam. Delft University of Technology. Diakses di scholar.google.nl/citations.

Bustomi, M., 2016. *Pengaruh Amblesan Tanah (Land Subsidence) Terhadap Luas Genangan Air Di Kota Semarang (Studi Kasus : Kecamatan Semarang Barat)*. Tesis Program Pasca Sarjana Universitas Islam Sultan Agung. Semarang.

Cernica, 1982. *Geotechnical Engineering-Soil Mechanics-Solution Manual.* Diakses opac.vimaru.edu.vn

Das, BM., 1998. *Mekanika Tanah (Prinsip-Prinsip Rekayasa Geoteknis) Jilid 2*. Erlangga. Jakarta.

Dinas Pekerjaan Umum. https://www.pu.go.id. Diakses pada 20 Agustus 2017.

Gumilar, dkk. 2009. *Sifat-Sifat Fisik dan Geoteknis Tanah (Mekanika Tanah)*. Erlangga, Jakarta. Hendrayana, H, 2002. *Dampak Pemanfaataan Air Tanah*. Diktat Kuliah Fakultas Teknik Jurusan Teknik Geologi. Universitas Gajah Mada. Yogyakarta.

Pratikso, 2013. *Bahan Ajar Mekanika Tanah II*. Diktat Kuliah Fakultas Teknik Sipil. Universitas Islam Sultan Agung. Semarang.