Landslide Mitigation of Banjir Kanal Semarang, with Grouting Method

Ansosry, H.A. Rahman, and F. R. Ramadhan

Mining Engineering Department, Faculty of Engineering, Universitas Negeri Padang, Prof Hamka Street, Padang 25131, Indonesia

Abstract. Indonesia is prone's country to the occurrence of mass movements. These disasters often occur in various regions, especially during the winter. Banjir Kanal is one of the locations of landslides from the observation in the field, the type of ground motion that occurs in the research area such as slump, it caused by the intense weathering of rocks and triggered by a condition of ground water level, Vibration, and human activities. Soil material at the research area such as claystone as the original soil and sandy clay stone as fill soil. The soil conditions and slope angle that very steep about 60 degree is a factors causing mass movement. The purpose of this research to determine the type of ground motion, causes and triggers of mass movement at the research area, and to know the success level of grouting methods to overcome them. The research method that used is descriptive method and experimental methods. Slope stability analysis used by the Fellenius method that calculated to determine the value of safety factor (Fs) at the study site. Based on the results of such simulations could be seen that after the implementation of grouting, soil cohesion increased.

1. Introduction
Mass movement is one of the most destructive natural disasters for human facilities and infrastructure every year. Mass movements can occur together with earthquakes, floods, and volcanic eruptions. However, local mass movements occur more frequently than mass movements caused by these disasters. Local mass movements often occur in road networks, irrigation, and infrastructure. Banjir Kanal Semarang is one of the efforts to carried out in the implementation of river normalization activities to facilitate the flow of surface water. In addition there is also a mission as a means of tourism. However, in some locations embankments have been made landslides which were also triggered by intensive weathering conditions. To repair the damage to the cliff and prevent the occurrence of advanced ground movements, the most appropriate method of handling is necessary.

the development of science and technology in the fields of geology and geotechnics, we must be truly capable and observant in determining the appropriate method for overcoming mass movements. Grouting is one of the new innovations that can be chosen as an effort to overcome soil movements that occur on the cliffs of Banjir Kanal. Grouting is a method of injecting cement paste into the soil with certain pressure passing through a drill hole to increase the strength of the soil. With the increasing strength of the soil, the slope of the slope can be maintained and the problem of ground movement that previously occurred can be overcome.
2. Literature Review

2.1 Regional Geomorphology and Stratigraphy

The physical condition of Semarang based on field observations morphology of the research area classified in the Alluvial Plain Formation Unit. The land forms from which fluvial processes are formed are due to river flow activity in the form of erosion, transportation, and sedimentation, where the processes which are carried out are also assisted by exogenous energy including climate, rainfall, wind, rock type, topography, temperature, all of which will accelerate the process of weathering and erosion. From these processes will form depositionional forms in the form of stretches of alluvial plains and other structures with horizontal structures, composed of fine-grained sedimentary material.[1][2]

The geology of Semarang based on the Regional Geological Map of Sheet Magelang and Semarang, Central Java composed of several Formations. Based on this classification the research area is classified into the Alluvium Unit (Qa). This unit is alluvium deposits of beaches, rivers and lakes. The lithology of beach deposits consist of clay, silt and sand with a thickness of 50 meter or more. River and lake deposits consist of gravel, glutony, sand and silt 1-3 m thick. The lump is composed of andesite, claystone and sandstone [5]

![Geological Map of Semarang and its Surroundings](image)

Figure 1. Geological Map of Semarang and its Surroundings (modified from Geological Maps of Sheets Magelang and Semarang) [5]

2.2 Landslide and Mass Movement

Mass movement is a downward or outward movement of the ground mass or slope constituent rock, as well as a mixture of the two as rags, resulting from the disruption of the stability of the soil or the rock constituent of the slope [2]. Other definition is reinforced by Suharyadi (2004), which mentions mass movement as a mass transfer of land or rock in the upright, flat or tilted direction from its original position, which is caused by an equilibrium disturbance at that time [3]. The process of the occurrence of soil movements along with the controlling factors and triggers can be seen in Figure 2.3 below.
2.3 Geotechnical Investigation

2.3.1 Core drilling

Core drilling is all types of drilling whose driving force is a machine. Core drilling can reach relatively deep subsurface conditions compared to hand drilling. The various parameters investigated in core drilling investigations include rock properties and quality. These various parameters can be obtained by analyzing the samples (cores) of the results of the surveillance (coring). Cores sample obtained are described by depth. The work of recording and drawing types of lithology according to depth is called logging. Includes physical properties of rocks to determine the carrying capacity of the soil against a technical construction that will be established. Land description is a statement that describes physical appearance and soil conditions, both samples and insitu, based on visual observations, simple tests, observations of field conditions, etc. [8]

| Description | Unconfined Compressive Strength (kg/cm²) |
|-------------|------------------------------------------|
| Very Soft   | < 0.25                                   |
| Soft        | 0.25 – 0.5                               |
| Firm        | 0.5 – 1                                  |
| Stiff       | 1 – 4.0                                  |
| Very Stiff  | > 4.0                                    |

2.3.2 Standard Penetration Test (SPT)

This standard specifies the method of field penetration testing with SPT, to obtain resistance parameters for soil penetration in the field with SPT. These parameters are obtained from the number of blows to cone penetration, which can be used to identify soil coating which is part of the design of the foundation. To get the N value by hitting the split spoon and drill handlebar circuit using a hammer weighing 140 pounds (63kg) of falling height 30 inches (75cm). Price N is the number of blows needed to split the spoon in as deep as 30 cm. The standard penetration test (SPT) is performed to determine the value of N (number of collisions in the rock layers tested). The greater the N value in the rock layer followed by an increase in the value of angle of repose (ϕ), the greater the value of the shear angle in the greater the value of rock bearing capacity. So that it can be said that the greater the SPT value will be followed by an increase in the value of the compressive strength.[6]
Table 2. Relationship between N (SPT) value and compressive strength [6]

| N (SPT) | Comments     | Strength (kg/cm³) |
|---------|--------------|-------------------|
| < 2     | Very Soft    | < 0.25            |
| 2 – 4   | Soft         | 0.25 – 0.50       |
| 4 – 8   | Moderately Soft | 0.50 – 1.00   |
| 8 – 15  | Firm         | 1.00 – 1.50       |
| 15 – 30 | Moderately Stiff | 1.50 – 2.00   |
| 30 – 50 | Stiff        | 2.00 – 4.50       |
| > 50    | Very Stiff   | > 4.50            |

2.3.3 Permeation Grouting
Permeation grouting is also called penetration grouting, which includes filling cracks, cracks or damage to rocks, cavities in the soil pore system and other porous media that aim to fill the pore space (cavity), without changing the formation and configuration or volume of the cavity. This type of grouting can be done for the purpose of strengthening the formation, stopping the flow of water through it, and Grouting penetration can increase soil cohesion [7].

![Grouting Equipment](image)

Figure 3 Grouting Equipment [7]

2.3.4 Slope Stability Analysis
In a place where there are two land surfaces with different heights, there will be diving forces so that the higher ground tends to move downward. In addition, there are also forces in the soil that work to resist or resist (resisting forces), so that the position of the land remains stable [4].
The driving forces are in the form of gravity, the force of the load or load, the pressure of the water in the pore and the disturbance on the slope that causes an avalanche. While the forces that resist are shear strength. The amount of shear strength is controlled by cohesion and internal friction angle between particles making up soil or rock. The cohesion value (c) depends on the strength of the bond or cementation between soil particles. The inner friction angle (ϕ) is a value that expresses the friction strength between rock constituent particles [2].
Based on the interaction between the two force moments, the stability of a slope can be calculated by comparing the resisting force and the eroding force (Bowles, 1991), which is formulated as follows

\[ Fs = \text{Resisting Force : Driving Force} \]  \( (I) \)

Fs is a slope safety factor, which is a value that expresses the level of stability of a slope. The slope will be stable if the force holding the motion is greater than the eroding force (Fs> 1). Critical conditions or slope
stability limits, if forces resist movement as strongly as eroding forces (Fs = 1). The slope will start moving if the force holding is small from the eroding force (Fs < 1).

3. Research Method

3.1 Literature Stage
The literature study phase includes collecting secondary data and reviewing literature related to regional geology and literature review that supports this research. The literature used is books related to geology, geotechnics, soil movements, slope stability and grouting, Semarang regional geological maps, Semarang regional technical geological maps, Semarang regional environmental geological maps, vulnerability zone maps of Semarang regional land movements, journals and from internet browsing.

3.2 Field Work Stage
Collection of primary data through field observation and investigation activities as well as core drilling samples at research sites at certain depths. At this stage of the field work a description of the results of core drilling is carried out at 4 points (PH1, PH2, PH3, and PH4) and 2 points after the grouting (CH1 and CH2) which are in the Plan Point WF.90R to WF.92R.

3.3 Laboratory Work Stage
At this stage laboratory tests were conducted on uninterrupted samples taken from the research area. Laboratory tests carried out include the Direct Shear Test and the Soil Properties Test. The results of laboratory tests produce data on the physical and mechanical properties of the material, bulk density (γ), angle of repose (φ) and cohesion (c). Sample testing and analysis was carried out in the Soil Mechanics laboratory, PT. Selimut Bumi Adhi Cipta.

3.4 Data Analysis and Processing Stage
The results obtained include:
- The slope geometry is presented in the form of slope cross sections along with the subsurface conditions
- Estimated shape and position of the critical slip plane
- Slope safety factor values (FS)

3.5 Integration Phase Results of Analysis and Interpretation
Integration between the results of data processing, field investigations, laboratory tests and secondary data and literature studies, was used to analyze the success rate of using the grouting method for controlling soil movements that occurred in Banjir Kanal. By using cohesion control parameters (c), a simulation is carried out to determine the value of slope safety factor (Fs) when there is ground movement. Interpretation is done by comparing the value of safety factors and cohesion when there is ground movement with conditions after grouting. From the results of the interpretation, it can be seen the success rate of the grouting work to cope with soil movements at the study site.

4. Result and Discussion

4.1 Land Investigation and Grouting and Laboratory Test Analysis
Soil investigation is carried out to determine the physical and mechanical properties of the soil. The data is obtained from testing the results of core drilling (coring) which is processed through tests in the laboratory. Analysis of soil mechanics laboratory tests carried out included water content tests, unit weight, specific gravity, and direct shear. Laboratory tests produce data on the mechanical properties of the soil, angle of repose (φ) and cohesion (c), as well as the physical properties of the soil, bulk density (γ). From the results of testing the six samples, the soil in the research location can be grouped into 2 layers, The following are the results of laboratory analyzes that have been carried out.
Grouting work is carried out to improve the feasibility of the soil in the area around Banjir Kanal, so that the soil conditions can be geotechnically engineered using the grouting method, which is a method of spraying / injecting fluid (cement) below the ground to increase the binding capacity between soils land that previously had a low cohesion value can turn into a land that has a very high bonding capacity between grains so that it can support the load.

| Table 3. Result of Laboratory Analysis |
|----------------------------------------|
| Laboratory Analysis | Before Grouting | After Grouting work |
|----------------------|-----------------|---------------------|
| Sandy clay layer     |                 |                     |
| $\phi$               | 21.38°          | 21.38°              |
| $c$                  | 0.061 Kg / cm²  | 0.061 Kg / cm²      |
| $\gamma$             | 1.701 gr / cm³  | 1.701 gr / cm³      |
| Clay layer           |                 |                     |
| $\phi$               | 13.69°          | 20.22°              |
| $c$                  | 0.156 Kg / cm²  | 0.312 Kg / cm²      |
| $\gamma$             | 1.701 gr / cm³  | 1.701 gr / cm³      |

Figure 4 Grouting activities at Point LA 27

4.2 Standart Penetration Test (SPT)

| Table 4.3 Standart Penetration Test Result |
|--------------------------------------------|
| No. | Hole | Depth (m) | Description               | Nspt |
|-----|------|-----------|---------------------------|------|
| PH (PILOT HOLES)                          |                     |                           |
| 1   | PH-1 | 4.5-5.0   | CLAYSTONE, brown, stiff   | 11-16|
|     |      | 9.5-10.0  | CLAYSTONE, grey, stiff    | 13   |
| 2   | PH-2 | 4.5-5.0   | CLAYSTONE organic, black, firm | 7     |
|     |      | 9.5-10.0  | CLAYSTONE organic, grey to black, stiff | 16    |
| 3   | PH-3 | 4.50-5.0  | CLAYSTONE sandy, grey to black, stiff | 7-10  |
|     |      | 9.5-10.0  | CLAYSTONE sandy, grey to brown, stiff | 13-16 |
| 4   | PH-4 | 4.5-5.0   | PASIR, black, stiff       | 9    |
|     |      | 9.5-10.0  | CLAYSTONE, black, stiff   | 10   |
|     |      | 14.5-15.0 | CLAYSTONE, black, very stiff | 30   |
Based on the acquisition of SPT Value that has been done (Table 4.3), it can be seen that the grouting method applied to the Location of the Banjir Kanal, increases the SPT value. The increase in SPT value which initially 7-16 increased to 14-23 after grouting.

4.3 Slope Stability Analysis
The cross section of the slope shows the slope geometry as it is in the field along with the soil / rock layers that make up it. This slope cut was obtained from direct measurements in the field and description of the results of core drilling, which was then made a design and sketch in the GeoStudio 2007 software so that it can be seen the level of slope stability before and after the grouting. In addition to obtaining security factor values, analysis using GeoStudio 2007 software also produces estimates of the shape and position of critical slip fields (critical circles) on the slopes, as shown in Figure 5 and Figure 6 below.

![Figure 5](image_url)

*Figure 5* Slope Stability Analysis before grouting using GeoStudio 2007
To determine the level of success of the grouting work, slope stability simulation was carried out. This simulation aims to find the value of slope safety factors when there is ground movement. From the simulation results it can be seen how much changes in soil cohesion at the study site during the movement and after the grouting is carried out. The control parameters used in this simulation are cohesion, because in principle the grouting work is done to improve the inter-grain bonding (cohesion) of the soil. Slope stability simulation was carried out by reducing the cohesion value of the soil condition after being gradually phased in with 21 simulated intervals with a value of cohesion increase of 0.078 kg/cm² in each soil layer. Changes in cohesion values are carried out continuously until the value of the comparison is more significant when there is a change in the value of c (cohesion).

Based on the processing of the simulated cohesion value (c) above, it can be seen that the grouting work to control soil movements in the location Banjir Kanal Semarang was declared successful. Sampling tested after grouting shows the effectiveness of the grouting work on the soil. The reaction of cement grouting
with soil is still ongoing and will increase in quality, so that soil cohesion can still increase. With increasing soil cohesion, the safety factor will also increase.

Acknowledgments
We thanks to PT. Selimut Bumi Adhi Cipta for the permission to do this research.

References
[1] Bemmelen R.W., Van, 1949, The Geology of Indonesia vol. 1A, The Hague. Gov. Printinf Office, Martinus Nijhoff, 732p
[2] Karnawati, D., 2005, Bencana Alam Gerakan Massa Tanah di Indonesia dan Upaya Penanggulangannya, Jurusan Teknik Geologi Fakultas Teknik Universitas Gadjah Mada, Yogyakarta
[3] Suharyadi, M.S., 2004, Pengantar Geologi Teknik Edisi ke 4, Biro Penerbit Teknik Sipil Universitas Gadjah Mada, Yogyakarta.
[4] Sunggono, K.H., 1982, Mekanika Tanah, Nova, Bandung.
[5] Thanden, R.E., Sumadirdja, H., Richards, P.W., Sutisna, K., dan Amin, T.C., 1996, Peta Geologi Lembar Magelang dan Semarang, Jawa, Skala 1:100000, Pusat Penelitian dan Pengembangan Geologi, Bandung.
[6] Terzaghi, K., Peck, R. B. 1987. Mekanika Tanah Dalam Praktek Rekayasa. Penerbit Erlangga, Jakarta.
[7] Warner, J., 2005, Practical Handbook of Grouting Soil, Rock and Structures, Mariposa, California.
[8] Wesley, L.D., 1977, Mekanika Tanah Edisi ke 6, Badan Penerbit Pekerjaan, Jakarta.