GEOLOGICAL ENGINEERING FOR HAZARD ASSESSMENT OF PAD AWI-14, SALAK FIELD, WEST JAVA, INDONESIA

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ABSTRACT

Locally steep slopes within the Salak geothermal field yield the possibility for large-scale landslides. During the heavy rains of 2003 Salak recorded significant slides that caused major damage and shut down a part of Salak operations for 3 months. Over the period 2010-2011 several new landslides have been identified around the Awi-14 injection location. The landslides have significantly impacted surface facilities including a pipeline, road, and well pad, and have the potential to impact injection strategy within Salak field.

The main contributing factors to the landslides in the area threatening the Awi-2 to Awi-14 pipeline were the steep slopes, high rainfall, and high porosity, loosely consolidated near-surface rocks. During periods of heavy rain the soil has the tendency to become over-saturated with water, triggering slope failure that can lead to soil creep or landslide depending on the nature of the underlying soil.

Several geotechnical analyses have been applied in 2011 to solve those problems, including shallow drilling for soil investigations, geological engineering mapping, geophysics survey, and finite element slope stability modeling. Those methods have helped to identified landslide mechanisms around the pad, quantify the risks at identified critical areas, provided recommendations for cost effective mitigation measures. Design and installation of both temporary and permanent landslide mitigation measures such as geo-textile, gabion baskets, bore pile / sheet pile, drainage systems were done to prevent occurrence of further landslides and restore the stability and viability of Awi-14 as an injection well in the Salak field.

1. INTRODUCTION

Salak field is located 60 km south of Jakarta in the West Java province, at an elevation between 1,100 - 1,500 meters above sea level (Figure 1). It is one of the world's largest liquid-dominated geothermal fields with a current total capacity of 377 MWe. Based on morphology this field located in a high terrain or mountainous area. The highest peaks are inactive andesitic volcanoes of Gunung Salak, Gagak, Perbakti and Endut that lie along the main trend of Sunda Volcanic Arc. Several fault also identified all over Salak area with dominant N-NE and subsidiary NW and E-W trending *(Stimac,et all 2008)*. This geologic circumstance leads the possibility of the area to have several kind of geohazard; one of the examples is landslide which have affected to Salak field assets.

Figure 1. *Location map showing Salak and Darajat geothermal field operated by Chevron*

Back to 2003 Salak field experienced series of landslides and debris flows that disrupted the production facilities capability to provide and control resource supply steam to PLN Power Plants Units 1, 2, & 3. The landslide created releases of brine, condensate and steam from pipelines, blocked access roads to well sites and created hazardous conditions to numerous operational locations, causing stopped operation activities for about 3 months. Specific to Awi-14 area, still in the same year 2003, landslides also occurred on the northern area of well pad, at that time Salak operation have immediately commenced implementing a remedial works program for the repair of damaged facilities and civil engineering infrastructure to improve pad stability *(Sagala, et all, 2003).*

During period of prolonged intense rainfall in the year of 2010, landslide reoccurred in well pad area Awi-14, this time landslide appeared in the cross country zone between this wellpad and Awi-2. Preliminary observation from resulted that most of landslides in this area considered to be due to a combination of concentrated run off related to erosion effects, together with a partial loss of soil strength (suction) caused by saturation of the soils. Hence detail geological engineering studies and slope stability analysis were needed to assess the most safety, most effective and effective programs to stabilize the area and mitigate further geohazard.

2. METHODOLOGY

On November 2010, landslide was identified at between brine lines AWI 2 to AWI 14. There are some cases to geotechnical issue found from preliminary observation such as identified landslide near pipe support where three trees fell down and shifted brine pipe line, other landslide observed along pipeline 40 m, width 24 m and subsidence 1.5 m depth, other landslide indication also discovered i.e. pipe line hanging, pipe support moved and tilted *(Kristianto, et all 2010)*. The brief recommendation at that time was covered landslide area with tarpaulin/ terram to stop water infiltration on unconsolidated soil surface, protected soil dirt spill to the Cibeureum River and avoided further slope erosion.

Figure 2. *Fallen tree and pipe movement on Awi-14 Awi-2 brine pipeline*

As a long term mitigation program, several geotechnical works were conducted in early 2011 prior the permanent engineering construction, the geotechnical works focus on the landslide area, in order to collate both surface and subsurface data (shallow), understand the soil characterization analyze rock strength and slope stability to develop representative geotechnical models for typical and critical sections of the slopes (Safety Factor). These models were then used as a basis for construction design.

The geotechnical investigations consist of:

- Fieldwork detail surface geological mapping to map out lithology, structure and landslide risk location (data combined from 2003 and 2011)
- Shallow borehole for soil investigation including, mechanical Cone Penetrometer Tests (CPT), Standard Penetration Tests (SPT)
- Laboratory testing. Soil properties analysis, also includes index properties, shear strength consolidation, and permeability tests.
- Shallow geophysical survey using 2D electrical resistivity and SP survey (Self Potential)

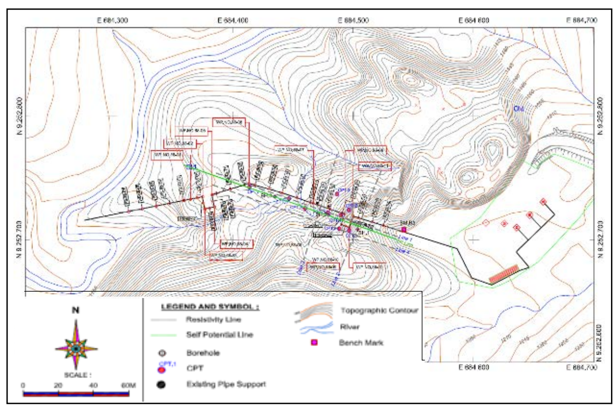

Figure 2. Layout location for CPT point, Borehole SPT, 2D Resistivity and SP geophysical survey

3. INTERPRETATION

3.1 DETAIL GEOLOGICAL MAPPING

From several observation spots during the mapping, landslide areas mostly consist of debris (colluviums), Orange Tuff, reworked Tuff and Lahar. These deposits mostly comprise weathered, with very low – low strength rock materials, and the Tuffaceous deposits are more typically fine-medium grained soils in accordance with standard engineering classifications.

Top soil has characteristics as soft, blackish brown, and root fragment. While the light brown, Orangeish to grayish brown Lahar, is the oldest geological unit encountered at the site, consists of Andesite, Dacitic and Tuff sub-angular to sub-rounded fragments up to cobbles to boulder size. The unit is commonly poorly consolidated, and occurs as silty gravel and boulder soil. Lahar layer is overlain by light brown, cream, brown and Orangeish reworked Tuff or transported Tuff characterized by firm to stiff or medium dense soil. This unit shows laminated and graded bedding structure.

Special explanation for Orange Tuff unit, which blanketed most of the site area (generally less than 3m in thickness) occurs as medium plasticity clay soil. Some thin intercalations of Silty Tuff frequently also occur within this unit. Hydrothermal processes have altered the Tuffaceous soils into light grey to blue grey, high plasticity, soft to firm clay which is an expansive or reactive soil due to the presence of montmorillonite (smectite) minerals, in other words Orange Tuff material usually stables in undisturbed condition but it becomes very sensitive to the water in disturbed condition. It also found that the landslide failure plane often coincides with the hydrothermally altered clay layer which occurs at the base of the Tuffaceous soil deposits.

As additional information to this study regarding alteration zone, there are most active thermal complex in Salak (Kawah Cibeureum) located on the north area of Awi-14 pad with distance of about 500m – 700m; and based on Salak geological map 2007, Cibeureum fault was confirmed existed at the side of Awi-14, with N-S fault trend, and passing Cibeureum mudpool area *(Stimac, et all 2007).*

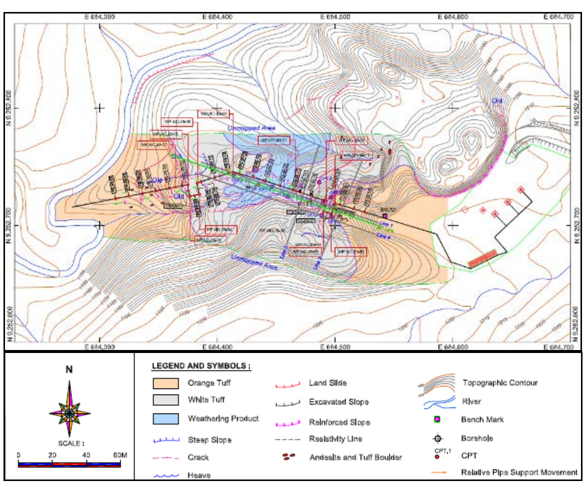

Figure 3. Geological Engineering Map at Landslide Area showing dominantly Orange Tuff at Awi-14

The typical of Tuff stratification in Salak area is following the original topography with various thickness, color and grain size. While some thin paleosoil is usually found between Tuff layers with various thicknesses.

During the field mapping, it was observed that a lot of drainage canals are left clogged with rock, soil and decaying organic materials. These prevent the free flow of water run-off during rains. The effect would thus be that water will overflow instead of being drained in a controlled manner, overflowing water will have the tendency of over-saturating the soil in the vicinity, triggering a chain of events that could lead to a bigger washout or worse a massive landslide depending on the nature of the underlying soil. Several soil movement indicators were also indicated at landslide area such as minor tension crack, heave, and water springs occurrence.

Raingauge monitoring added information about high intensity of rain was observed in Salak field prior the landslide happened. It was strengthen the preliminary interpretation during geological fieldwork that mechanisms of landslide in Awi-14 were most likely related to poor drainage which resulted uncontrolled water runoff (from high intensity rain), induced a structural deformation (crack) and triggered slope failure during heavy rain season.

3.2 SOIL INVESTIGATION

In order to gain direct information about the soil character beneath surface, then geotechnical soil investigation should be conducted. The works consisted of Cone Penetration Test (CPT) and shallow drilling with SPT.

The CPT cone test has been carried out at 9 points, utilizing DCPT device of 2.5 tons capacity in accordance with ASTM D3441-75T. The cone resistance value and local friction or friction sleeve value has been observed at every 20 cm depth interval. The penetration speed is maintained at approximately 2 cm/sec. Those tests have been performed to reach cone resistances value > 160 Kg/cm2.

Figure 4. Soil investigation activity Awi-14

CPT work resulted a graph that shown the correlation of ground layer depth and the value of :

- Cone penetration (kg/cm2)
- Local friction (kg/cm2)
- Total friction (kg/cm1)

Shallow drilling and SPT works also conducted for total depth 25 meter that is performed at 3 point of boreholes. Standard Penetration Test (SPT) has been performed at 2 meter interval. Number of blows for sample penetration of 1 foot was recorded for each test. The weight of hammer is 63.5 kg. The hammer used in this test shall be free from friction using effective device according to ASTM D 1586-58T. The sampler used in SPT has an outside diameter of 51 mm and an inside diameter of 35 mm and length of 810 mm. The CPT, borehole and SPT result was shown below (Fig 5)

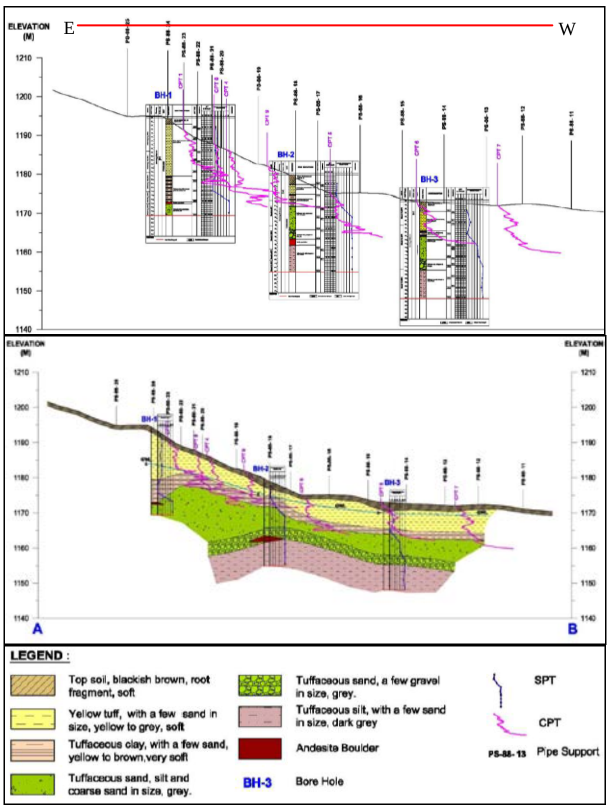

Figure 5. Data and interpretation for CPT and Shallow Drilling Log BH-01, BH-02 and BH-03 in cross section along the slope and pipeline (E to W)

The drilling locations has been chosen as representative as possible. Using Toho D2G single core rotary machine, a shallow drilling activities has been carried out to soil investigation. The machine could drill up to 150 m depth. The outer diameter of the core barrel is 89 mm. This is entirely performed to obtain a reliable and efficient recovery sample.

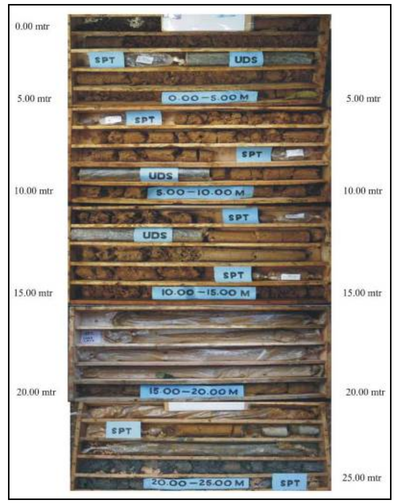

Figure 6. Soil sample from BH-01

Soil investigation results from BH-01, BH-02, and BH-03 samples, showed that there are six layers of soil units:

a. At the top layer of soil formation consisted mainly of soil blackish brown with root fragment with SPT or N-value of this layer varied from 2 to 6 blows/ft
b. Second layer is Orange to brown Tuff in sand size SPT or N-value varied from 3 to 26 blows/ft
c. Third layer is Orange to brown Tuffaceous clay, with minor sand, , very soft SPT or N-value is 1 blow/ft
d. Fourth layer is Tuffaceous sand, silt and coarse sand in size, grey with SPT or N-value varied from 13 to > 60 blows/ft
e. Fifth layer is grey Tuffaceous with sand and gravel, SPT or N-value varied from 25 to 60 blows/ft
f. Sixth layer is dark grey Tuffaceous silt with sand, SPT or N-value varied from 17 to > 60 blows/ft.

3.3 2D RESISTIVITY & SP SURVEY

The electrical resistivity is one of geophysical techniques that use variations of electrical resistivity value to determine subsurface material. This method is carried out by injecting current into the ground through the steel current electrodes and measuring potential difference using steel potential electrodes. The aim of injecting current and measuring potential difference is to determine the resistivity value distribution beneath the electrical resistivity line. The electrical resistivity survey is conducted in four lines

Data result has been converted from apparent resistivity to inverted resistivity using numerical inversion program. The inverted resistivity data has been conducted to construct subsurface profile based on electrical properties of material. The vertical axis indicated the elevation and the horizontal axis indicated the horizontal distance along the line. The color in the cross section showed the distribution of electrical resistivity value.

The model inversion result at line 1 showed that a high resistivity value is detected from 70 meter to 105 meter, which is indicated intensive fracturing area. A low resistivity value is indicated massive clay / very fine tuff. The model inversion result at line 2 showed that there is no structure features in this line. A high resistivity value is indicated Tuffaceous sand. Orange tuff layer is distributed at top layer (Fig7).

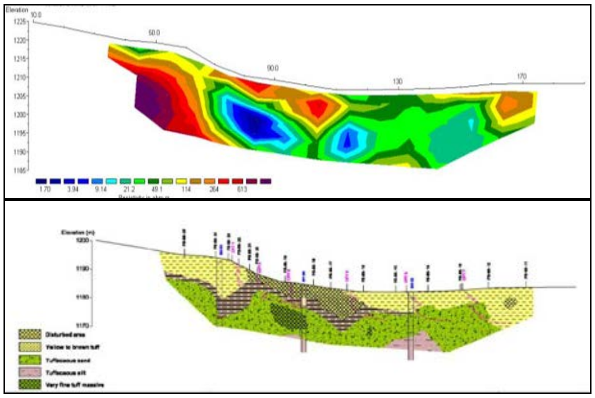

Figure 7. 2D resistivity Inversion model and Soil profile interpretation from Line-1

The model inversion result at line 2 showed that there is no structure features in this line. A high resistivity value is indicated tuffaceous sand. Orange tuff layer is distributed at top layer. From the line 3 showed that there is clearly indicated of landslide movement. A high resistivity value is indicated tuffaceous silt. A low resistivity value indicated tufaceous clay with highly fracturing area is occupied at top layer, which is indicated by high value resistivity at top layer. Line 4 showed that there is clearly indicated of landslide movement, a high resistivity value indicated an intensive fracturing area and low resistivity value indicated very fine tuff / massive clay in this location.

As addition from geophysics survey, a single line of self potential survey performed along pipeline route at AWI 14. The SP line has been conducted through length 225 meter parallel to pipeline route.

The SP survey resulted anomaly profile and the fluctuating potential differences occurred from beginning measurement to last failure pipe support. Indicate that there was intensive fracturing filled with water. The constant potential difference is occurred from several spot, which indicated dry area. At the end of line, there is a high anomaly that possibly spring water.

3.5 LABORATORY TEST

Laboratory test on recovery samples (undisturbed soil). The following tests have been carried out:

- Index properties
- Grain size analysis
- Atterberg limit
- Tri-axial UU
- Tri-axial CU
- Direct shear

All the laboratory test was utilize as input data for geotechnical and slope stability analysis as conclusion for this study.

4. CONCLUSION AND RECOMMENDATION

Prior the geotechnical assessment several mitigation program had been conducted to stabilize the area temporarily. Covered the landslide plane with tarpaulins, and geotextile were completed immediately after landslide discovered to stop water infiltration to unconsolidated soil surface. And then as part of permanent restoration program, geotechnical assessment were carried out, to understand more soil properties and geotechnical parameters from Awi-14 slope area, the assessment consist of detail topographic, geological mapping, 3 shallow boreholes (up to 25 meter depth), 9 points of CPT, laboratory testing, and geophysics survey. All the data from those assessments will become main input for qualitative geotechnical analysis.

Table 1. Soil design parameter based on geotechnical data of BH-01 - BH-03 and CPT-1 to CPT-9

Layer	Thickness (m)	Soil type	N-SPT	CPT (kg/cm3)	Cohesion
1	0 - 2	Top soil, soft clay	-	4-12	10-20
2	Varies, max 13	Orange Tuff, medium stiff	6-18	14-30	50-90
3	1 - 2	Tuffaceous clay, very soft to stiff	1	18-40	10-30
4	Varies, >8	Tuffaceous sand/ silt, very dense/hard	>60	>150	180

From all geotechnical analysis it was confirmed that main cause of geohazard or landslide within Awi-14 area was due to steep slope relief and genuine soil condition surrounding location which dominated by colluviums, loose pyroclastic product (Orange Tuff, reworked Tuff and some Lahar), during mapping also found that these deposits mostly weathered and having very low to low strength rock materials, coupled with poor drainage uncontrolled water run-off from heavy rainfall, then overflowing water will have the tendency of over-saturating the soil in the vicinity, triggering a chain of events that could lead to a slope failure, bigger washout or worse a massive landslide.

Geological engineering recommendation was to build an effective drainage system within this location, in purpose to ensure stability of the permanent engineering pile and also prevent surface runoff infiltrating the landslide debris mass at the base in front of the landslide head scarp.

The quantitative slope stability analysis also carried out to complete the assessment, using PLAXIS Version. That geotechnical analysis 2D program is a finite element package specially intended for the analysis of deformation and stability in geotechnical engineering projects. PLAXIS is equipped with special features to deal with the numerous aspects of complex geotechnical structure, as Mohr-Coulomb model, advanced soil models, excess pore pressure, stage construction and safety factor. Based on slope stability analysis, the factor of safety (SOF) of the slope will be recognized and landslide reinforcement project could be done within good justification.

The stability analysis conducted to critical slope section and performed in four stages as follow:

1. Slope Stability Analysis for existing slope after failure, no reinforcement design.
2. Slope Stability Analysis after Pile Installation, Potential landslides still exists and may damaged bored-pile foundation.
3. Slope Stability with Pile Foundation of Pipe Support, Potential landslides still exist
4. Slope Stability area with Soldier Pile as Slope Reinforcement

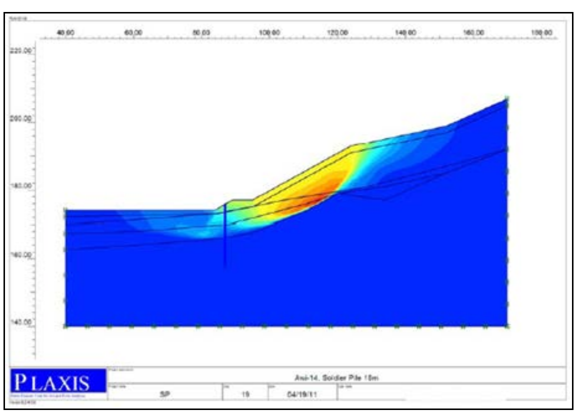

Figure 8. Slope stability and stress deformation analysis using finite element for Soldier Pile as slope reinforcement

With combination and comparison four stages of analysis above, the best design for reinforcement program was installation of soldier-pile with 18 meter of length, from those analyses it is indicated that the soldier pile will located below failure area and possibly could secured the area. In the end of 2011, construction of sheet pile and the drainage improvement were done and succeed to stabilize the area, support Awi-14 as injection well area.

Figure 9. Implementation of the engineering construction Soldier pile as permanent landslide restoration in 2011 - 2012

After the restoration program, to maintain the stabile condition, several works also recommended to be applied in Salak field, including evaluation of hazard potential area, conduct routine geotechnical monitoring (including installation of inclinometer for subsidence measurement in hazard potential area) and the last recommendation is prevention program which held based on risk priority from geohazard GIS map analysis.

In the end, the author need to say that all analysis and recommendation is only valid when the geotechnical assessment lasted, the slope stability condition could slightly change according to time.

5. ACKNOWLEDGEMENT

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