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SOIL STABILIZATION USING HORIZONTAL DEEP DRAINAGE AT AWI-14 BRINE LINE PIPE AND WELL PAD, STAR ENERGY GEOTHERMAL SALAK FIELD, WEST JAVA, INDONESIA

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ABSTRACT

Salak geothermal field has several locally steep slopes that could yield the possibility for large-scale landslides. During heavy rains on 2003, Salak recorded significant landslides that caused major damage and shut down a part of Salak operations for 3 months. Over the period 2010-2012 several new landslides have been identified around the Awi-14 injection location. The landslides have significantly impacted surface facilities including pipeline, road, and well pad, and will have a potential to impact injection strategy within Salak field.

Steep slopes, high rainfall, high porosity, and loosely consolidated near-surface rocks were the main contributing factors to the landslides in the area that will threatening the Awi-14 brine line pipe. During heavy rain, the soil has the tendency to become over-saturated, triggering slope failure that can lead to landslide depending on the nature of the underlying soil.

On 2011, several geotechnical analyses have been applied including shallow drilling for soil investigations, geo-electrical, geological engineering mapping, and geophysics survey. Those applications have helped to identified landslide mechanisms around the pad, quantify the risks at identified critical areas, and provided recommendations for cost effective mitigation measures. High groundwater level at Awi-14 brine line pipe has identified as the main problem, it has decreased the soil strength so one of the solution is to lowering the groundwater level. Design and installation of Horizontal Deep Drainage (HDD) systems were done for lowering the ground water level. This method would prevent occurrence of further landslides and restore the stability and viability of Awi-14 as an injection well in the Salak field.

Keywords: Salak, Awi-14, geothermal, geohazard, landslide 2010, geotechnical analysis, geological engineering, construction

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 MW. 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 (James Stimac, et.al, 2007). 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 Star Energy

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 (URS Indonesia, 2004). Specific to Awi-14 area, still in the same year 2003, landslides also occurred on the northern area of Awi-14, 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,Birean, et.al, 2003).

During period of prolonged intense rainfall in the year of 2010 and 2015, landslide and soil subsidence reoccurred in well pad area Awi-14, this time landslide appeared in the cross country zone between this well pad and Awi-14 and at northern site of well pad, precisely behind sheet pile area. 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.

METHODOLOGY

On November 2010, landslide was identified at between brine lines Awi-2 to Awi-14 (Figure 2). 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 3 m depth, other landslide indication also discovered i.e. brine line pipe hanging, pipe support moved and tilted (Gunawan, Adi, et.al, April 2011). 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 (Salak Operation, 2010 – 2011).

As a long term mitigation program, several geotechnical works were conducted in early 2011 (Figure 3) 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)

Hereafter on December 2015, subsidence case also happened at northern of Awi-14 well pad behind of sheet pile (Figure 4). Soil subsided 1 to 2 m depth and shifted the sheet pile 2 to 3 m away from well pad.

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

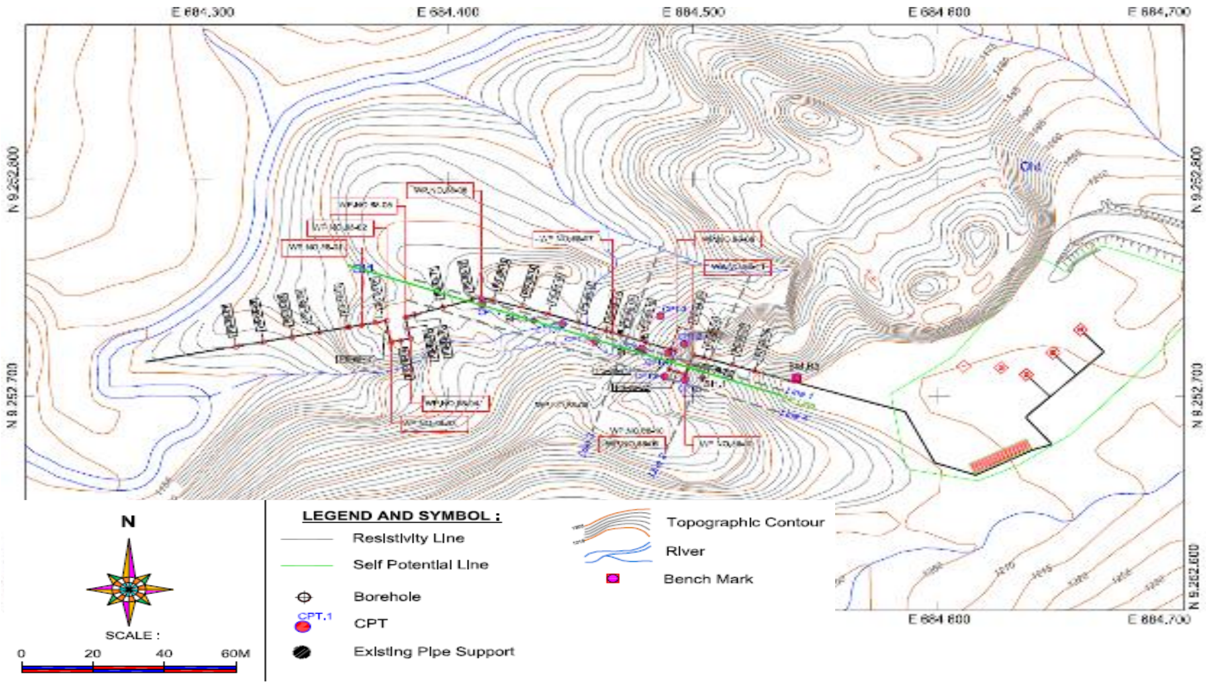

Figure 3. Layout location for CPT point, Borehole SPT,2D Resistivity and SP geophysical survey

Figure 4. Soil subsidence and sheet pile shifting at Awi-14 well pad

Rain gauge monitoring added information about high intensity (52 mm/hour) of rain was observed in Salak field prior the landslide happened (Salak Operation, December 2010). It was strengthen the preliminary interpretation during field study that mechanisms of landslide in Awi-14 were most likely triggered by the significant rise of the groundwater level and therefore by the dramatic changes in the subsurface stream of the groundwaterr (Figure 5 & Figure 6). High groundwater level 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.

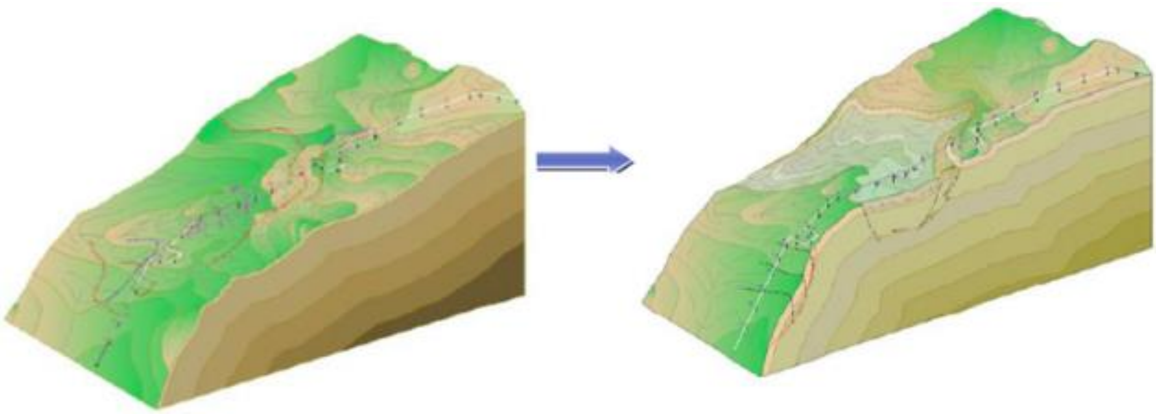

Figure 5. Left picture is original topography and right picture is a translational landslide that occurred acrosss Awi-14 brine line pipe route, wtih slip failure at 10m below ground level (measure from BH-3)

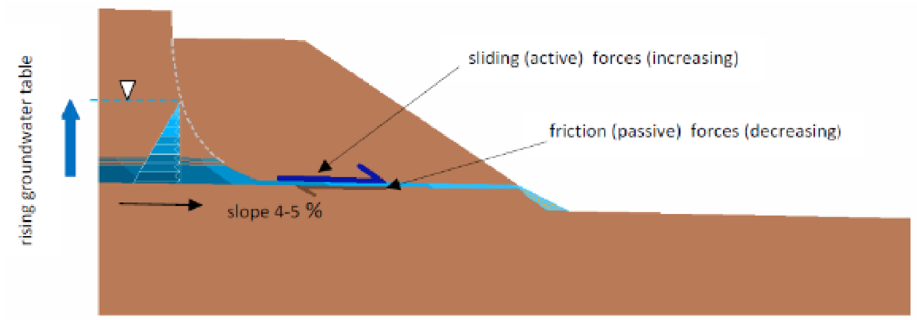

Figure 6. Cross section showing the increasing of active sliding forces, decreasing of passive friction forces, and rising of hydrostatic pressure

INTERPRETATION

Detail Geological Mapping

From several observation spots during the mapping, landslide areas mostly consist of debris (colluviums), Orange Tuff, reworked Tuff and Lahar (Figure 7). 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 (Figure 8) 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 mud pool area (Stimac, et.al, 2007).

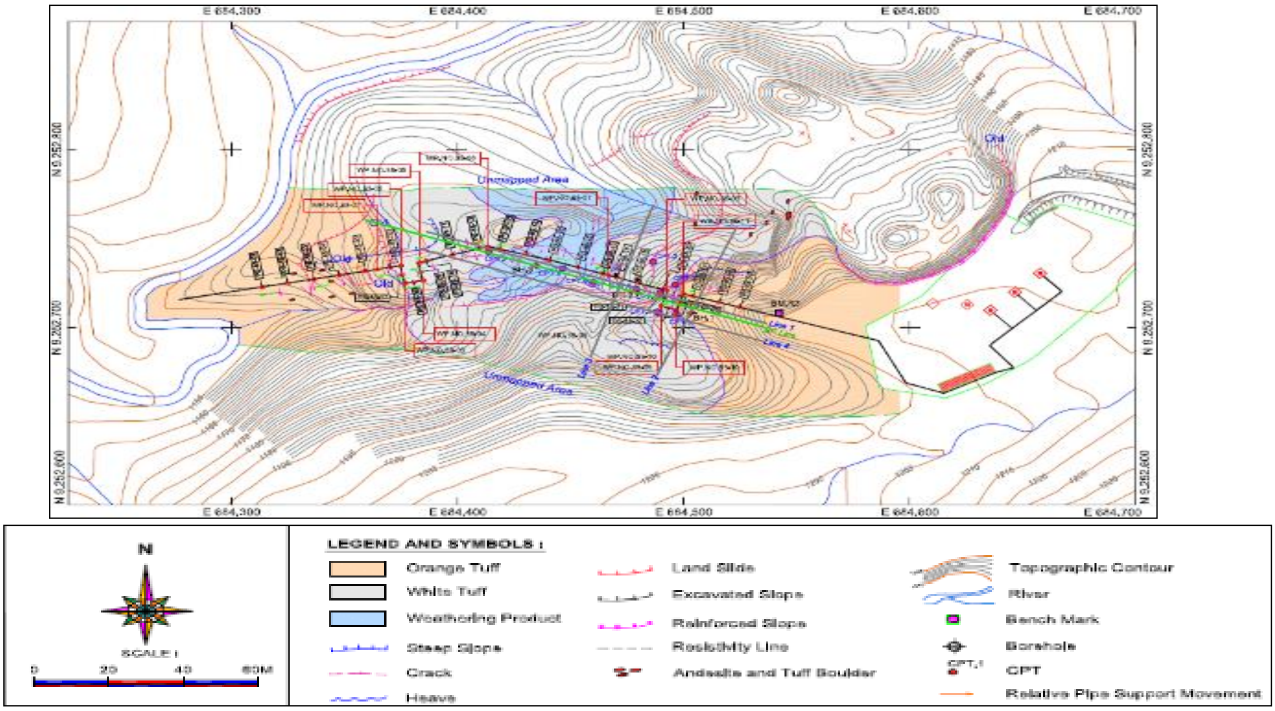

Figure 7. Geological Engineering Map at Landslide Area showing dominantly Orange Tuff at Awi-14

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.

Figure 8. Orange tuff in core box

Soil Investigation

In order to gain direct information about the soil character beneath surface, then geotechnical soil investigation should be conducted (LAPI ITB, 2011). The works consisted of CPT and shallow drilling with SPT (Figure 9).

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

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Figure 9. Soil investigation activity Awi-14 pipeline

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 & SPT works also conducted for total depth 25 meter that is performed at 3 point of boreholes. 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 & an inside diameter of 35 mm and length of 810 mm. The CPT, borehole & SPT result shown below (Figure 10)

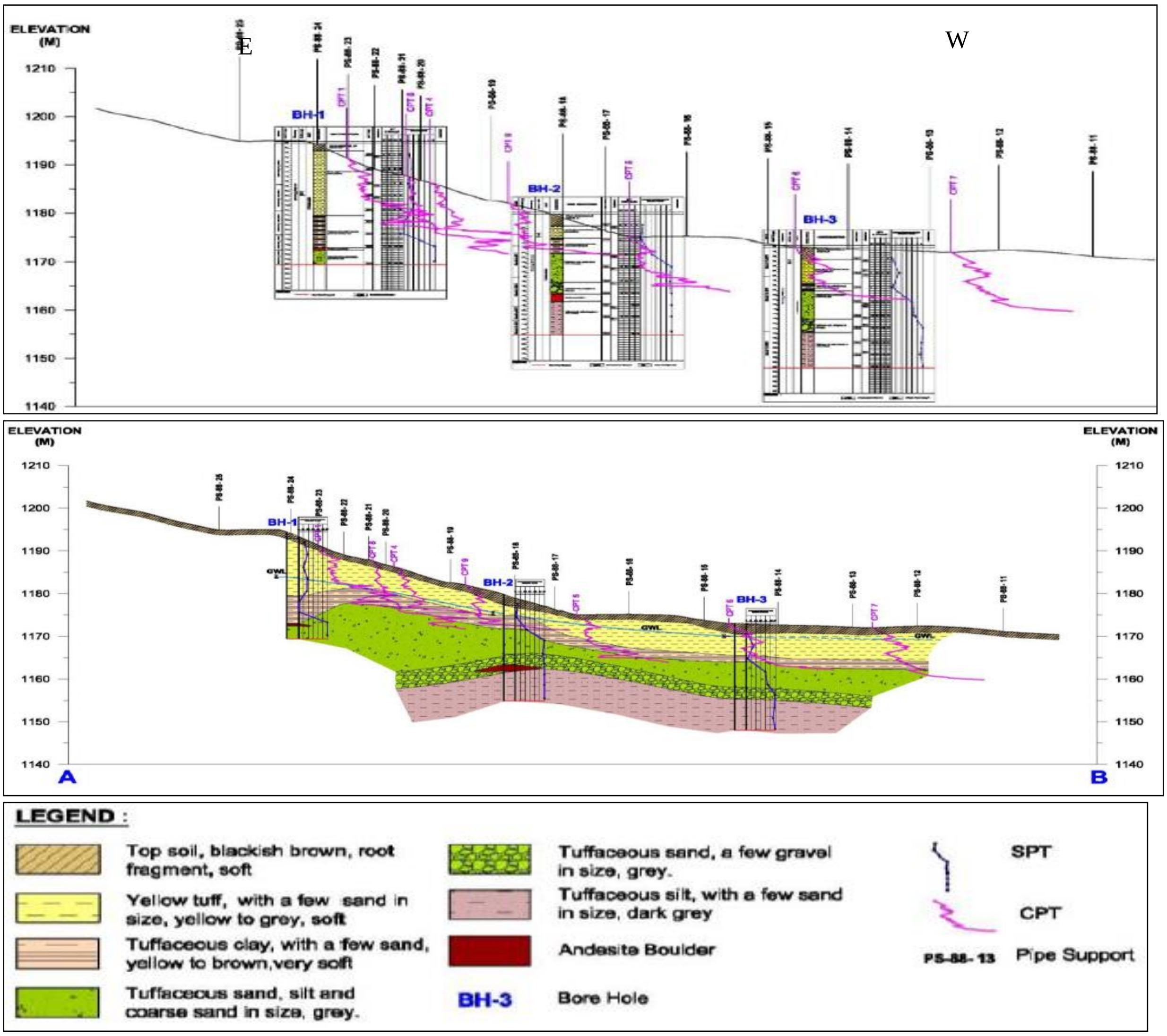


Figure 10. Data & interpretation CPT & Shallow Drilling Log BH-01, BH-02, & BH-03 in cross section along the slope & Awi-14 pipeline (E to W)

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.

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

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 1 blow/ft
d. Fourth layer is Tuffaceous sand, silt & 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 & 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.

2D Resisitivity, SP SURVEY, & Sr (%)

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 (Figure 11).

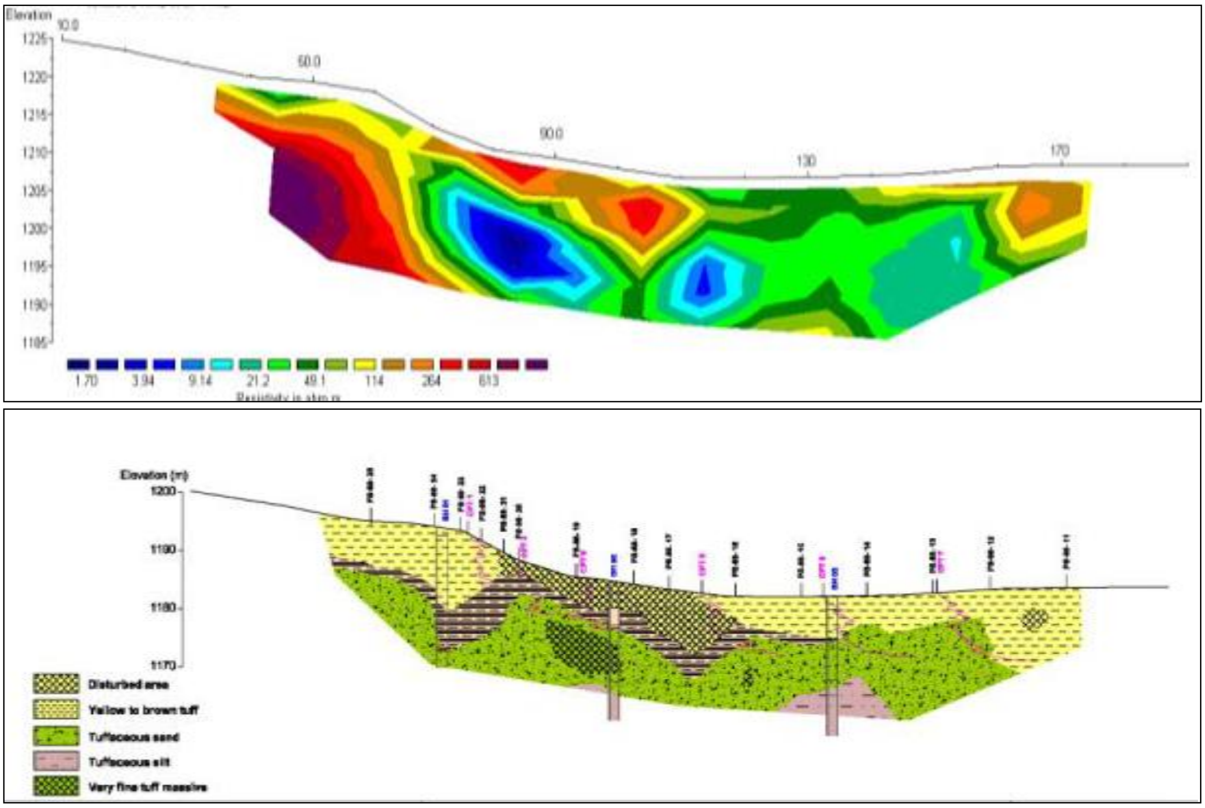


Figure 11. 2D resistivity Inversion model and Soil profile interpretation from Line-1of Awi-14 pipeline

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 (Figure 12). High ground water table potentially exist at soil under Awi-14 pipeline

High saturated degree or Sr (%) was got from laboratory test that taken from soil data at Awi-14 well pad (Figure 13)

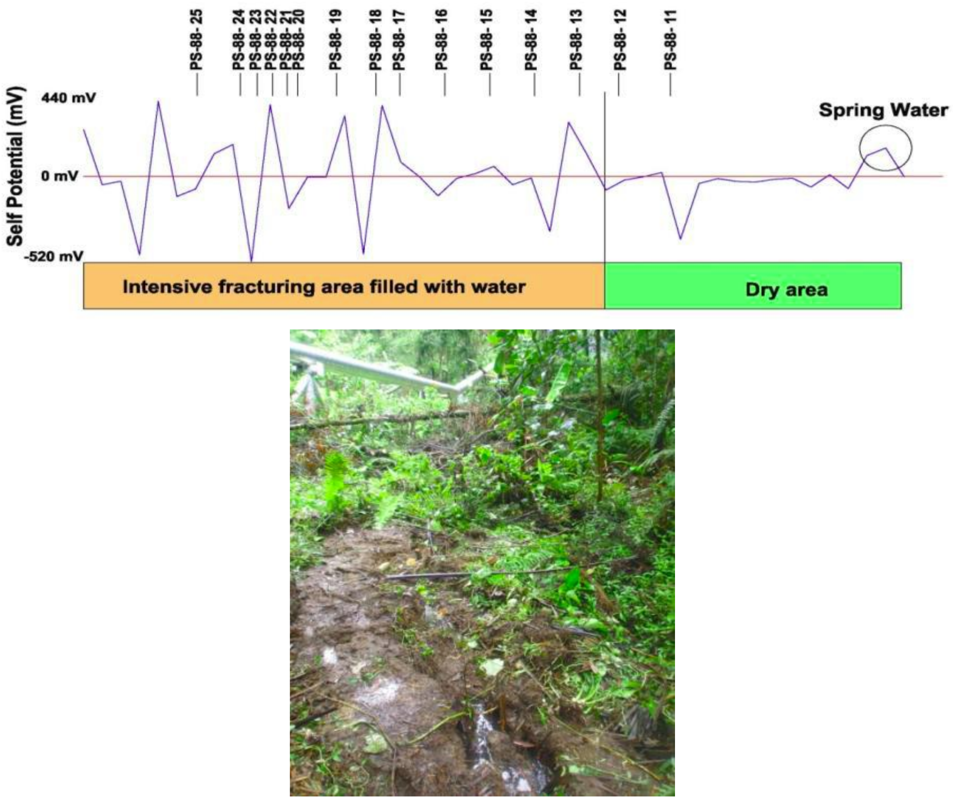


Figure 12. Self-Potential profile at crack area along Awi-14 brine line pipe, crack filled with water

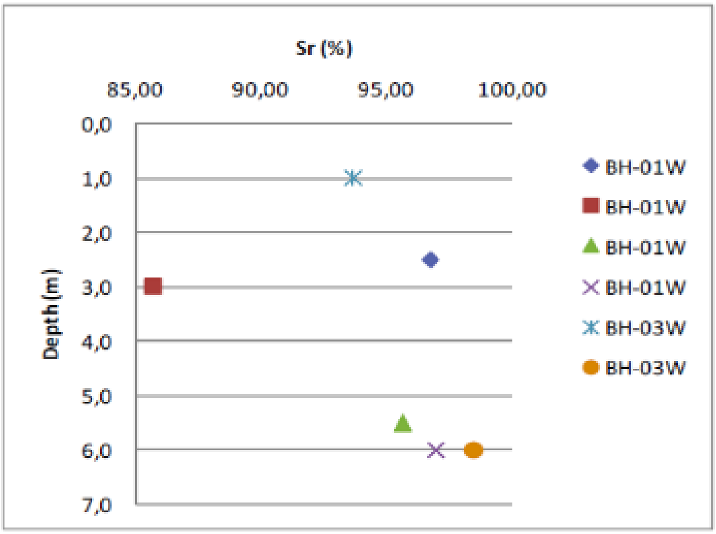


Figure 13. Sr (%) for various depth at Awi-14 well pad taken from BH-14-01-W & BH-14-03-W

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.

CONCLUSION

From all geotechnical analysis it was confirmed that main cause of geohazard or landslide within Awi-14 area was due to steep slope relief, high ground water table, and genuine soil condition surrounding location which dominated by orange tuff with soil characteristic silt and coarse sand so dewatering is the appropriate solution to increase the slope stability safety factor (JACOBS, 2014). The orange tuff usually stable in undisturbed condition but it becomes very sensittive to the water in disturbed condition. During mapping was found that these deposits (orange tuff) 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.

These types of landslides had been triggered by the significant rise of the groundwater level, and therefore by the dramatic changes in the subsurface stream of the groundwater, several cases the sliding soil volume is so enormous (sometimes several hundred-thousands m³) that is it nearly impossible to stop it with engineering structures (or if is it possible, the costs are extremely high). The efective systems to stabilize and prevent this type of landslide is the Horizontal Deep Drainage (HDD) as a perfect tool to minimize the water table level (Istvan Szemesy, 2011). Technical reason of using this method can explain as below formula interpretation:

$$\tau = \sigma' \tan(\varphi') + c'$$

where,

τ = soil shear strength
φ' = soil friction angle
c' = soil cohesion

σ' = $(\sigma - u)$
= effective soil stress
σ = total soil stress
u = pore water pressure that correlated with ground water level (h_w)

Soil shear strength (τ) will be increase if effective soil stress (σ') increase so in condition of landslide triggered by high ground water level or high pore water pressure (u), the best solution is to decrease pore water pressure (u) and this condition will only been achieved by lowering ground water level (h_w).

Awi-14 brine line pipe landslide restoration project was executed on November 2014 with scope of work: installation of five (5) line of HDD that consist of horizontal drilling and installation of perforated HDPE pipe 6", while Awi-14 well pad restoration project was executed on May 2016 with only two (2) line of HDPE perforated pipe 6" installed (Figure 14). Horizontal drill machine type DDW-500C with pull back capacity 50 ton was used to execute this project, the work sequence as following flow chart (Figure 15).

Prior horizontal drilling, pilot bore plan must be provided. This bore plan will ease the operator to track the drilling distance, elevation, and angle of drilling in accordance with HDD design layout plan and elevation (Figure 16 and Figure 17). Completed installation of HDD has shown the result of water release from landslide area (Figure 18). This condition will improve the slope safety factor.

Figure 14. Horizontal drilling activity and HDPE perforated pipe 6" preparation before pulling back

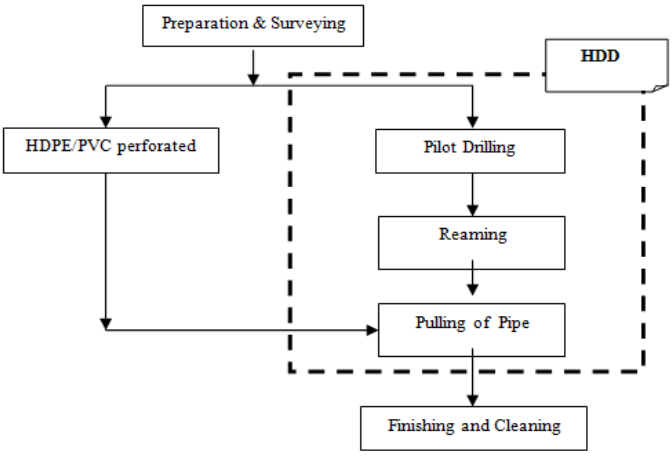


Figure 15. Horizontal drilling activity and HDPE perforated pipe 6" installation flow chart

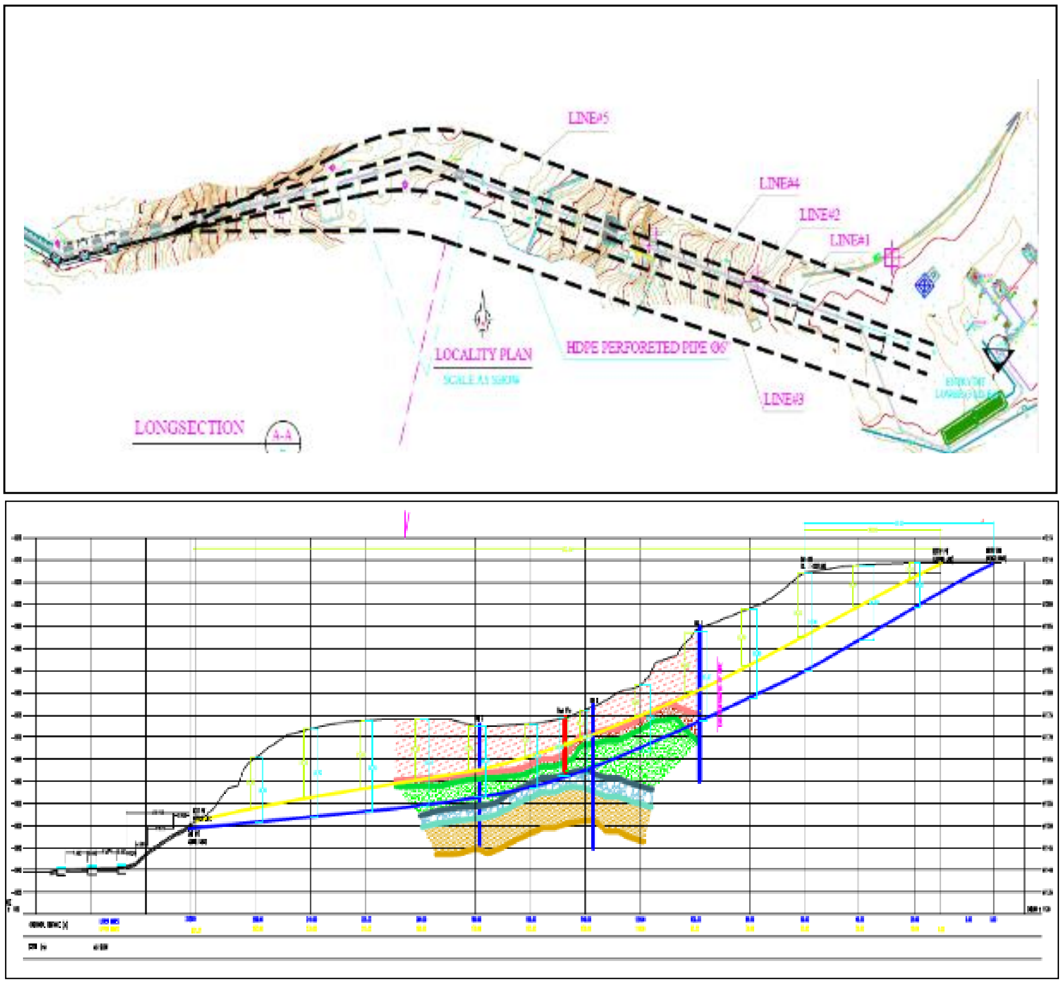


Figure 16. Five (5) line of Awi-14 brine line pipe horizontal deep drain layout and cross section

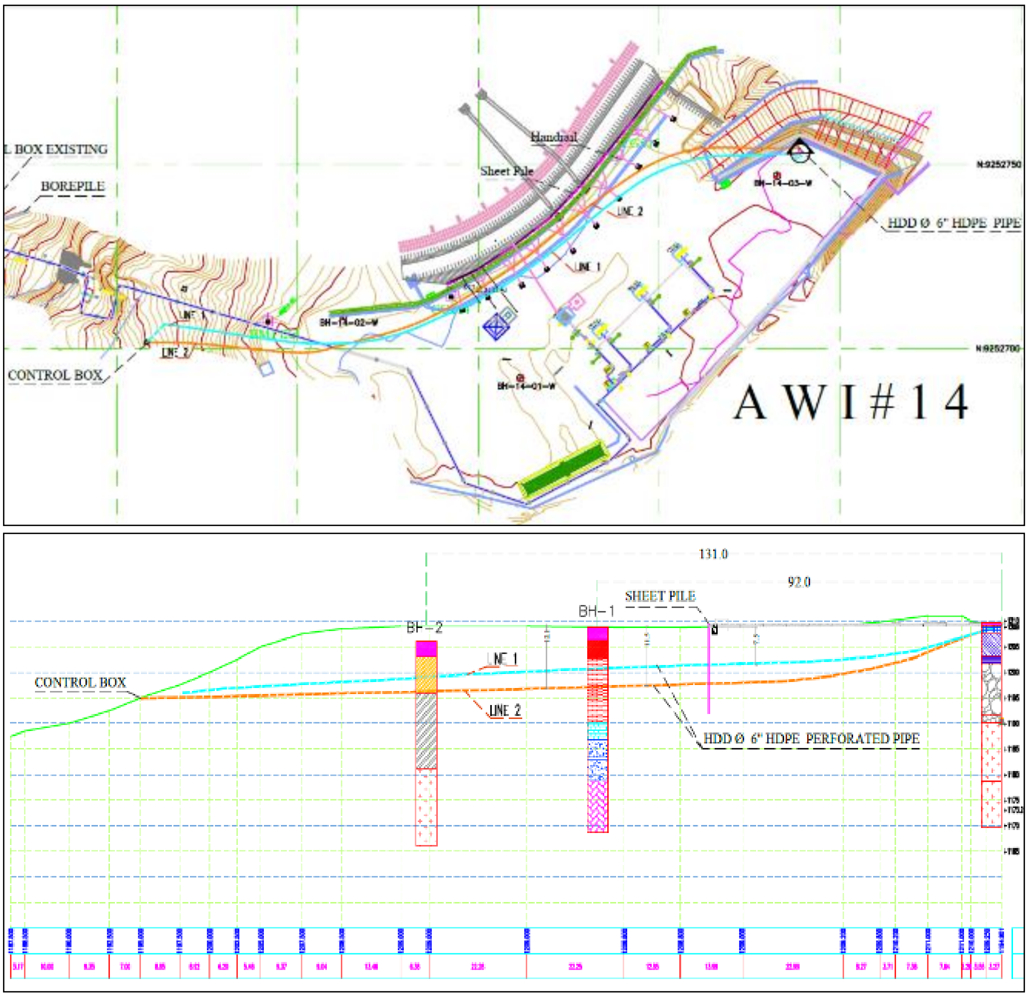


Figure 17. Two (2) line of Awi-14 Well pad horizontal deep drain layout and cross section

Figure 18. Completed installation of five (5) line of HDD at Awi-14 brine line pipe (left photo) and two (2) line of HDD at Awi-14 Well pad (right photo). Those HDD has successfully dropped ground water level

Prior the installation of HDD, measurement ground water level has conducted (Figure 19) in order to have a baseline data. To measure the ground water level, project team has installed one (1) unit vibrating wire piezometer and one (1) unit stand pipe piezometer. Those two (2) piezometer installed near bore hole 3 (BH-3) as the highest ground water level that measure during soil investigation. After HDD installed, ground water level dropped drastically to the level that expected -13 to -15 m. It could be read from piezometer that installed (Figure 20)

Water Level Monitoring BH1,2,&3 at Brine Line AWI 14

Date		2011	2012													
		Maret	November		Desember											
		16	28	29	4	5	6	7	8	9	10	11	13	15	17	18
Brine Line																
Water level Monitoring from surface (m)	BH-1	10,8	7,1	7,7	7,65	7,7	7,9	7,87	7,9	7,8	7,7	7,7	7,8	8	8	8
	BH-2	3,6	2,3	1,58	1,62	1,69	1,68	1,67	1,65	1,45	1,6	1,45	1,48	1,63	1,6	1,62
	BH-3	3,55	0,27	0,17	0,46	0,5	0,65	0,49	0,46	0,46	0,45	0,44	0,44	0,42	0,4	0,4

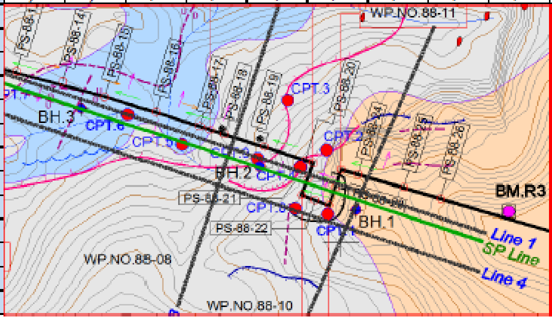
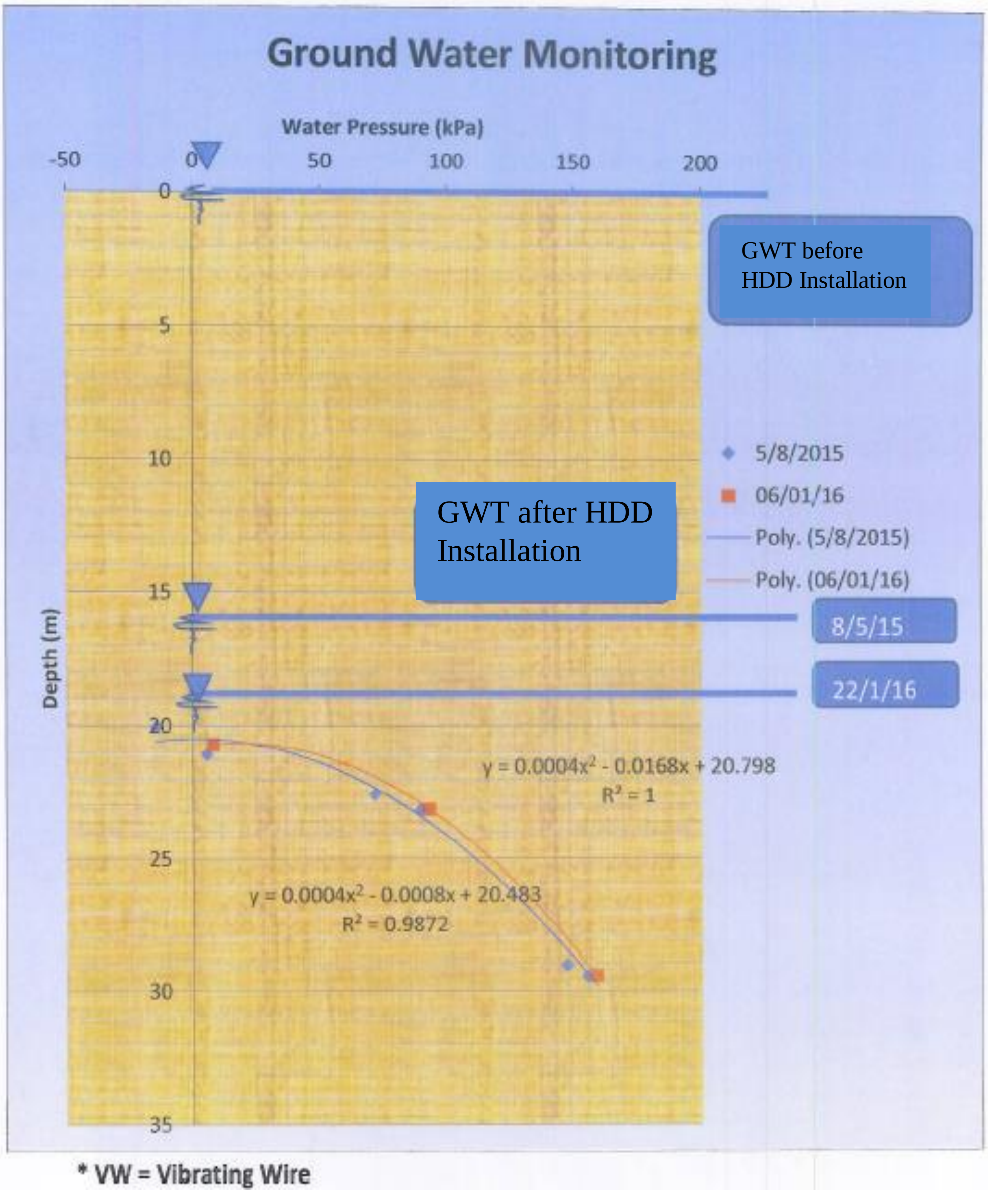


Figure 19. Table of GWT level measurement at AWI brine line prior HDD installation



No	Month	Date	Weekly	Water Level below ground surface (m)			Water Pressure (Ton/m²)		
				SP (25m)	SP (15m)	SP (5m)	SP (25m)	SP (15m)	SP (5m)
1	July	7/10/2015	1	13.4	12.5	NA	11.6	2.5	NA
		7/15/2015	2	13.2	12.6	NA	11.8	2.4	NA
		7/20/2015	3	13.2	12.6	NA	11.8	2.4	NA
		7/30/2015	4	13.2	12.9	NA	11.8	2.1	NA
2	August	8/10/2015	1	13	12.9	NA	12	2.1	NA
		8/15/2015	2	13	13.3	NA	12	1.7	NA
		8/20/2015	3	13.1	13.3	NA	11.9	1.7	NA
		8/30/2015	4						

* SP = Stand Pipe

Figure 20. Data of GWT level and hydrostatic pressure taken from vibrating wire piezometer and stand pipe shown the decreasing of GWT after HDD installed

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REFERENCES

James Stimac, et.al, 2007. "An Overview of the Awibengkok Geothermal System, Indonesia", Geothermics.

Gunawan, Adi, et.al, April 2011, "Report of Landslide Mitigation on Awi-2 and Awi-14 Brineline Area", Internal Presentation Report for Chevron Geothermal Salak

LAPI ITB, 2011, "Report of Soil Investigation at Landslide Area – Awi-14", Prepared for Chevron Geothermal Salak

Salak Operation, 2010 - 2011 "Routine Geohazard and Subsidence Monitoring", Internal Report for Chevron Geothermal Salak

Salak Operation, December 2010 "Salak Weather Monitoring", Internal Report for Chevron Geothermal Salak

Sagala, Birean, et.al, 2003, "Report on Soil Structure Investigation Awi-14 Pad Location", Internal Report for Chevron Geothermal Salak

URS Indonesia, 2004, "Salak Recovery Project Landslides Assessment", Prepared for Unocal Geothermal of Indonesia, Ltd.

Istvan Szemesy, 2011, "Stabilization and prevention of water triggered landslides", 10-th Slovak Geotechnical Conference

JACOBS, 2014, "Awi 14 Existing Brine Line Restoration", Design Review Report (ZP01581-RPT-GE-100 | A) prepared for Chevron Geothermal Salak, Ltd.