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Mitigating the Impact of Landslide Hazards in PNOC-EDC Geothermal Fields

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ABSTRACT

Landslides and slope failure hazards are common in PNOC-EDC geothermal fields, which are located mostly in steep mountainous terrain. This situation is further aggravated by the presence of inherently weak clay-altered ground and sometimes fumaroles and mud pools above the slopes. From being mere road nuisances, these landslides had become an enormous threat to PNOC-EDC operations because these could cut-off pipelines, and even obliterate a geothermal well pad resulting to plant shutdowns thus, loss of revenue. Various approaches were implemented to address these hazards and were grouped into four main categories, namely: 1) avoidance, 2) protection/prevention, 3) acceptance, and 4) remediation. Some of the remedial measures that were carried out include benching, drainage control, structural barriers and vegetative stabilization. Prior to construct these engineering measures, a hazard assessment is first undertaken to properly address the problem. Regular audit and review of these remedial actions were continually made for each project sites creating checklists to comparatively assess if such measures were adequate. Additional hazard assessments were done if the works were inadequate and or if new slide prone areas were identified. For critical sites such as transmission towers, extensometers and tilt meters were installed for constant monitoring of any slope movement.

1. INTRODUCTION

The high temperature geothermal fields (Fig. 1) of PNOC-EDC are mostly located in volcanic areas that are characterized by high relief, rugged terrain and high rainfall rate. Landslides and slope failure hazards are therefore not uncommon in the project sites. This situation is further aggravated by the presence of inherently weak thermally altered rocks and sometimes fumaroles and mud pools above the slopes.

Landslides denote a generic term for any slope deformation, which includes slumps, rockfalls/rockslides, debris, slides, debris avalanches and earthflows. The term sheetslide is also applied for movements of shallow slope debris, loam and weathering materials on the surface of the bedrock (Zaruba and Mencl, 1982). An imperceptible movement called creep usually precedes these deformations.

The consequences of these landslides vary depending upon the severity of the damage inflicted on PNOC-EDC's infrastructures. From mere road nuisances, landslides became an enormous threat to PNOC-EDC's operations as some had already cut-off pipelines and even obliterated a geothermal well pad thus exacting heavy toll and revenue losses to the company. The following record shows hundreds of millions of pesos already spent by the company for almost a decade due to landslides.

Coping with these landslide hazards therefore has been one of the major concerns of PNOC-EDC.

This paper aims to present the PNOC-EDC's experience in dealing with the landslide phenomenon and associated slope deformation hazards, the hazard assessment methodology, the engineering measures undertaken, and the continuing effort to mitigate the impact of landslides.

2. HAZARD ASSESSMENT TECHNIQUE

Prior to establish the engineering measures, a hazard assessment is first conducted to properly address the problem. In PNOC-EDC, the degree of slope instability was assessed using the evaluation scheme adopted for tropical environments by Lee and Juang (1992), which was modified for practical applications in Philippine geothermal fields. The technique employs relevant factors that control the stability of slopes such as geology, general slope condition, environment and hydrogeology. Each primary factor is given corresponding secondary level factors with an assigned qualitative weight (Table 2). From these factors, a set of criteria is established for qualitative determination of the degree of instability (Tables 3, 4, 5, 6).

The failure potential ranking of a specific area can then be qualitatively classified by summing up the assigned ratings (A,B,C,D,E) for each secondary level factors which will be further evaluated against the primary factors. The slope instability ranking is given in Table 7.

The above evaluation is supplemented by the use of aerial photographs to determine the geomorphological and general geological characteristics of an area. In the case of predominantly rocky slopes, Rock Mass Rating (RMR) techniques, as well as joint and microfault measurements for kinematic admissibility analysis are also used in assessing slope instability.

After the field assessment, a map is generated assigning areas with slope failure potential rankings. Figure 2 is an example of a landslide hazard zonation map of the Mindanao Geothermal Production Field (MGPF).

3. STRATEGIES AND ENGINEERING MEASURES

In dealing with landslide hazards, various approaches were being implemented by PNOC-EDC. These methods are grouped into four main categories, namely: (1) avoidance, (2) protection/prevention, (3) acceptance, and (4) remediation (modified after Hausmann, 1992).

3.1 Avoidance

This is usually undertaken during the early stages (e.g. planning stage) of a project. Landslide hazard assessments are first conducted in a specific area especially along the proposed pipeline routes, peripheries of pads, power plant sites and control centers so that identified high-risk areasare avoided during actual construction of facilities and road network.

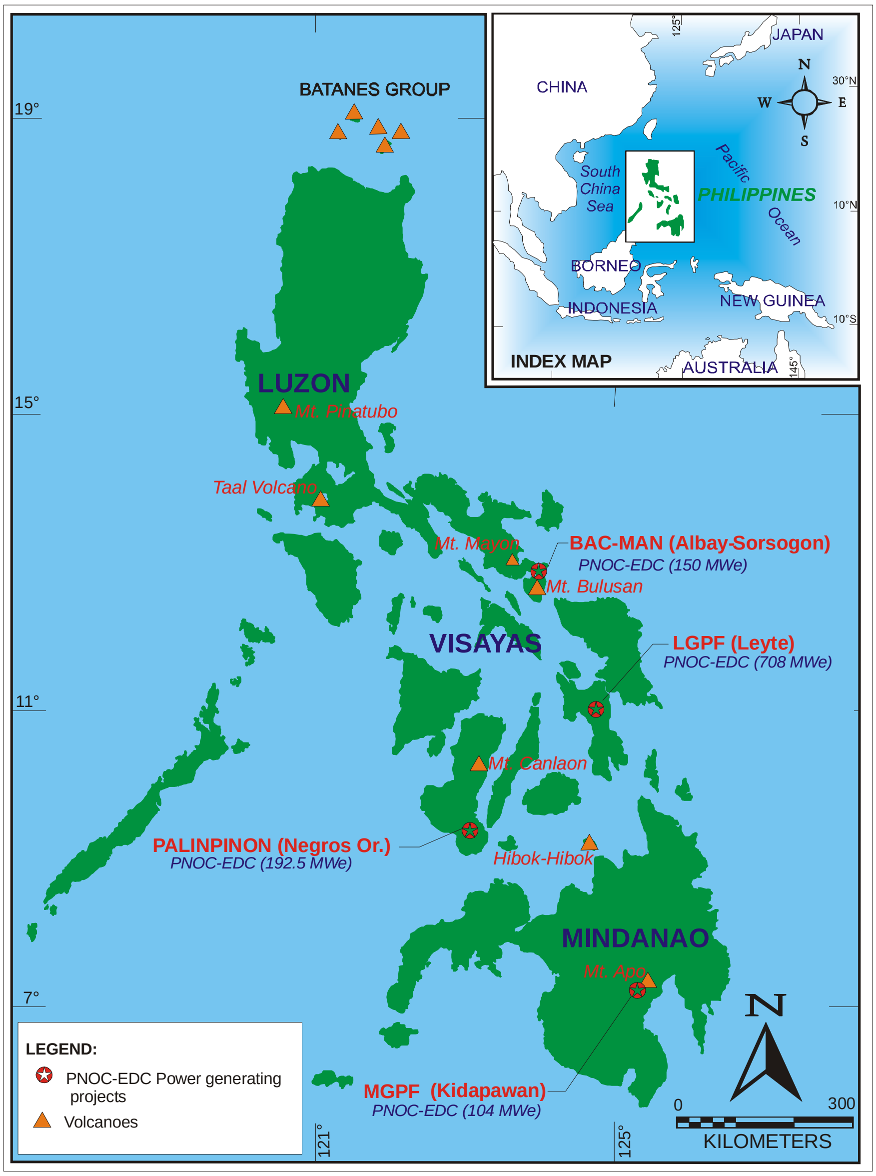

Figure 1: Map showing PNOC-EDC's various operating geothermal fields

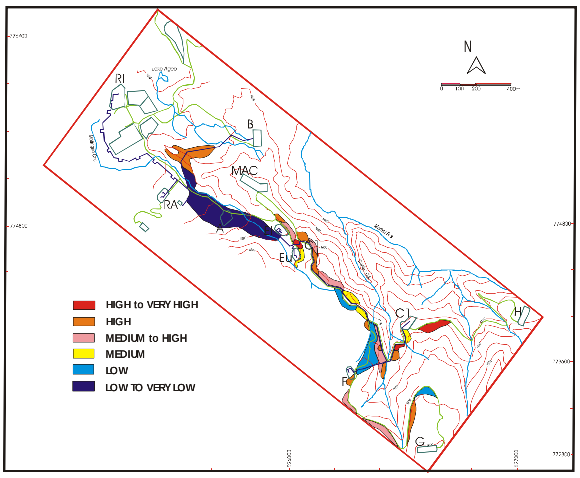

Figure 2: Landslide hazard zonation map of the PNOC-EDC's Mindanao Geothermal Production Field (MGPF) showing slope failure potential rankings

Figure 3: View of one of PNOC-EDC's reforestation project near the Mindanao Geothermal Production Field (MGPF).

3.2 Protection/Prevention

The objective here is to limit the potential for slope failures rather than try to repair the damage after the event. Good land management prevents undue mass wasting. Revegetation of bare slopes and opened up areas and other soil conservation measures help in minimizing surface erosion and siltation of waterways. By declaring a specific locality as protected, all developments should cease and anthropogenic activities such as farming, slash and burn type of agriculture or kaingin should be curbed. Through the efforts of the environmental management group of PNOC-EDC, there are reforestation projects and forest protection activities being implemented within and outside the geothermal projects and even the surrounding watersheds (Fig. 3)(Pioquinto, 1999).

3.3 Acceptance

The detrimental effect of slope movements could be reduced or eliminated if landslides could be induced in really susceptible areas or the sliding mass diverted to an area of least danger to decrease the effect or rightly eliminate such risk (Fig. 4). In case of rockslides and rockfalls, galleries or pipe shelters could be constructed to protect the concerned installation (Fig. 5).

3.4 Remediation

Remediation is aimed to stop or reverse the destabilizing process using engineering measures. These measures are further classified into the following: (1) changing the geometry of the slope, (2) control of surface water and seepage, (3) rigid structural barriers, (4) flexible support structures, and (5) vegetation.

Figure 4: Photo shows the slide materials coming from the Mag-aso thermal ground in the Southern Negros geothermal field being diverted to a large culvert below the road.

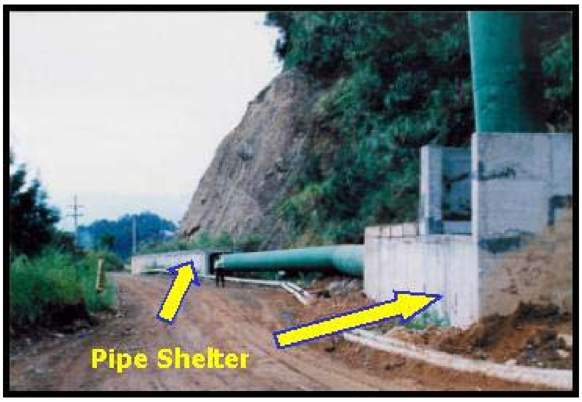

Figure 5: Pipe shelters were installed along some portions of the FCRS route above pad E in MGPF as this site is prone to rockslides and rockfalls.

The first remediation technique was employed in the Leyte Geothermal Production Field (LGPF) at the former Mahiao quarry area. A sliding mass was detected as the toe support was removed due to quarrying. The solution therefore, was to reduce the load above the sliding mass and benching of the slope was undertaken to prevent further slippage. Figure 6 shows the removal of the upper load along the slope of the quarry face. The second scheme, control of surface water and seepage was applied in the Malitbog quarry area also in LGPF where concrete water cascades were constructed to minimize water saturation of the formation. The more common remediation technique employed at PNOC-EDC is the construction of rigid structural barriers such as rubble masonry wall and concrete retaining wall with concrete-lined canals. Figures 7 and 8 show examples of these structural barriers (Leynes et al., 2002).

Figure 6: This is the quarry in Upper Mahiao in LGPF where the upper load was reduced and the slope face benched to prevent further slippage.

Figure 7: Picture shows a newly constructed masonry wall along the Mahanagdong-MGRD1B access road in LGPF. A pipe shelter is in the far left. These were

constructed to protect the pipeline from landslides occurring in the right side of the road.

Figure 8: This is the massive concrete retaining wall constructed near the OK-5 pad periphery in SNGPF where a former landslide obliterated the OK-5 geothermal well pad. Note the bare slopes above the slide planted with trees and the concrete-lined canals beside the wall.

Figure 9: Old tires were overlain here in this photo near NJ-A pad periphery in SNGPF to reinforce the toe of the slope where a former landslide had occurred.

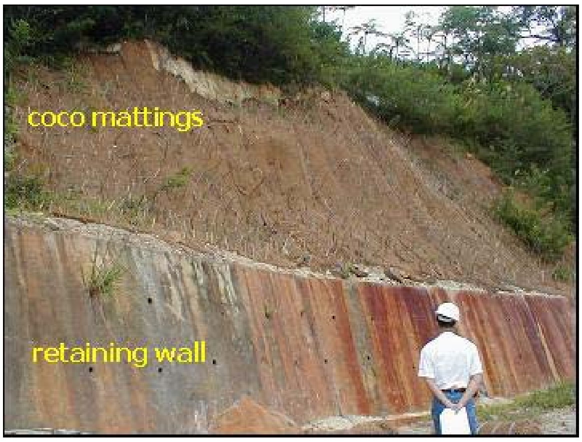

Figure 10: The view shows an example of vegetative stabilization in combination with rigid structural barriers being implemented in SNGPF near NJ-A pad. Here, coco mattings were installed to promote revegetation of the bare slopes above the retaining wall.

A flexible support structure is also constructed in combination with the rigid structural barriers. An example of this was implemented in the Southern Negros Geothermal Production Field (SNGPF), Nasuji sector as shown in Figure 9. Old tires were overlain at each other to arrest a sliding mass near the pad periphery. Lastly, vegetative slope stabilization projects have been quite a common practice of PNOC-EDC. Various tree and grass species are planted to bare slopes as well as backfilled portion beside roadcuts. A Filipino technology using coco mulches, mats and fascines has been integrated along with the rigid structural barriers to mitigate a landslide prone area. Shown in Figure 10 is an example of that scheme where bare slopes are eventually revegetated as soon as enough soil accumulates along the slopes to decrease pore water pressure and seepage.

4. HAZARD MONITORING

It is imperative in PNOC-EDC to conduct regular audit and review of the remedial measures that were previously undertaken. This is done in order to effectively gauge the effectiveness of the engineering measures that were implemented and also to update the previous assessment of the area regarding slope failure potential rankings. Semi-annual inspections at each project sites were usually done and the resulting evaluation is communicated to concerned groups. A landslide task force composed of PNOC-EDC personnel from different groups was also created at each project site to promote a pro-active stance and vigilance to monitor or mitigate the impact of impending landslide.

In the case of critical sites such as transmission towers, extensometers and tilt meters were installed for constant monitoring of any slope movement. Extensometers are instruments that provide a measure of the ground movement by measuring the displacement of a device from a fixed reference point. The data from extensometers can thus be the basis for a quick response to an impending landslide. Currently, an extensometer is installed in Tower No.7 area of LGPF (Fig. 11) (Leynes et al., 2002). If there is a discrepancy of current data with the baseline, a team will readily inspect and evaluate the site. This is to ensure the proper response whether the slope movement detected necessitates immediate action or drastic decision such as relocation of that specific facility.

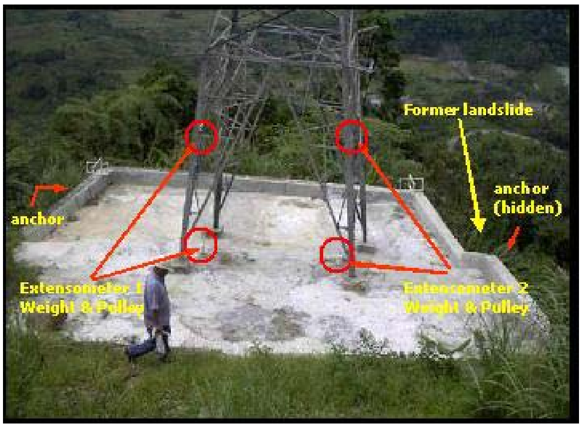

Figure 11: This is the power transmission tower (Tower No. 7) in LGPF where extensometers were installed near the tower footing. These instruments continuously monitor any slope movements below the concrete base of this critical structure where a former landslide had occurred.

5. SUMMARY AND CONCLUSIONS

Landslides are undoubtedly deleterious to the geothermal operations in PNOC-EDC areas. The damages and consequent business interruptions already contributed substantial losses to the company over the years so that PNOC-EDC has taken efforts to mitigate the impact of this landslide phenomenon. The management has taken up steps to develop effective procedures in dealing with these slope instabilities. Figure 12 below summarizes the process on how PNOC-EDC handles these hazards.

Regular audit and inspections of the engineering measures undertaken and update of the hazard assessment of the area will still be PNOC-EDC's continuing effort to mitigate the impact of landslides in the different geothermal fields. The critical sites such as transmission towers and other important facilities will have to be constantly monitored as well for any impending slope failures that may damage these structures.

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Table 1. 1994-2003 PNOC-EDC loss record due to landslides and associated business interruptions (after PMD, 2004)

	Date of Loss	Particulars	Location	Amount (in million U.S. dollars)	Total
1994					1.140
	January	Landslides[1]	BGPF	0.613	
	August	Landslides[1]	MGPF	0.140	
	December	Landslides[1]	LGPF	0.387	
1995					3.986
	September	Landslides[1]	LGPF	0.430	
	October	Landslides[1]	NNGP,LGPF	1.306	
	November	Landslides[1]	MLGP,BGPF	1.239	
	December	Landslide	BGPF	1.011	
1997					0.042
	December	Landslide	SNGP	0.042	
1998					2.851
	October	Landslides[1]	SNGP	1.254	
		Business Interruption[3]	SNGP	1.577	
	December	Landslides[1]	LGPF	0.020	
2000					1.173
	February	Landslide	BGPF	0.129	
	May	Landslides[2]	LGPF	0.455	
	October	Landslides[1]	BGPF	0.255	
	November	Landslides[1]	LGPF	0.334	
2001					4.394
	February	Landslides[1]	LGPF	3.142	
	August	Landslides	MGPF	0.508	
	October	Landslides	MGPF	0.111	
		Business Interruption[3]	MGPF	0.633	
2003					0.778
	July	Landslides[1]	LGPF	0.778	
Grand Total					**14.364**

(1)landslides associated with typhoon, (2)landslides associated with earthquake, (3) business interruptions caused by landslides, BMGPF (Bac-Man Geothermal Production Field, LGPF (Leyte Geothermal Production Field, MGPF (Mindanao Geothermal Production Field), MLGP (Mt. Labo Geothermal Project), NNGP (Northern Negros Geothermal Project, SNGPF (Southern Negros Geothermal Production Field)

Table 2: Factors Adopted for Slope Instability Rating (modified after Lee and Juang,1992)

Primary Level factor	Weight	Secondary level factor	Weight
A. General Slope Condition	EI*	A1. Slope gradient/inclination A2. Slope height A3. Slope direction A4. Deformation intensity A5. Age of deformation A6. Activity of deformation A7. Type of slope material	EI EI I I I EI VI
B. Geology	VI	B1. Rock type B2. Weathering grade B3. Orientation of discontinuity B4. Spacing of discontinuity B5. Rock mass B6. Presence/condition of faulting B7. Presence of altered grounds	VI VI VI EI VI VI VI
C. Environment	EI	C1. Type of vegetation C2. Density of vegetation C3. Type of land use C4. Type of protection facility C5. Drainage facility	I VI EI VI EI
D. Hydrogeology	EI	D1. Seepage D2. Permeability of top soils D3. Presence of water course	EI I VI

*EI- Extremely important, VI- Very important, I- Important, NVI- Not very important, UI- unimportant

Table 3: Criteria for Assessing Slope Instability based on Slope Condition (modified after Lee and Juang,1992)

Secondary level Factor under slope condition	**Criteria for Evaluating Slopes**				
	A*	**B**	**C**	**D**	**E**
A1. Slope gradient (°)	40-60	30-40/60-70	>70	20-30	<20
A2. Slope height	>20	5-20	-	2-5	0-2
A3. Slope direction	Towards (area concerned)	Oblique	Parallel	-	Opposite
A4. Deformation intensity	great	Unimpressive	Unclear		Insignificant/ none
A5. Age of deformation	recent	Fossil	-	-	-
A6. Activity of deformation	active	dormant	stabilized	Removed/ buried	None/insignificant
A7. Type of slope material	Landslide material/ uncompacted fills	Clayey earths or weak semi-solid rocks	-	Semi-solid rocks	Solid rocks

*A- VERY HIGH , B- HIGH, C- MEDIUM, D- LOW, E- VERY LOW

Table 4. Criteria for Assessing slope Instability based on Geology (modified after Lee and Juang,1992)

Secondary level Factor under geology	Criteria for Evaluating Slopes				
	A	B	C	D	E
B1. Rock type	Unconsolidated pyroclastics	Laharic mat'ls	-	Volcanic breccias	Lavas
B2. Weathering grade	Completely weathered or residual soil	Highly weathered	Moderately weathered	Slightly weathered	Fresh
B3. Discontinuity orientation	e-w or parallel to concerned area and dipping towards	Oblique and dipping towards	perpendicular	Dipping opposite	-
B4. Discontinuity spacing (cm)	<6	6-20	20-60	60-200	>200
B5. Rock mass	crushed	irregular	Columnar/ tabular	blocky	Massive
B6. Presence/ condition of faulting	Active, <50m from concerned area	Active, >50m	Inactive, <50m	Inactive, >50m	None
B7. Presence of clay and or acid-altered grounds	Predominantly clay-altered	Moderately clay altered	Slightly clay altered	-	None

*A- VERY HIGH , B- HIGH, C- MEDIUM, D- LOW, E- VERY LOW

Table 5. Criteria for Assessing Slope Instability based on Environment (modified after Lee and Juang,1992)

Secondary level Factor under environment	Criteria for Evaluating Slopes				
	A	B	C	D	E
C1. Type of vegetation	No cover	grass	Grass > trees	-	-
C2. Density of vegetation	Very low (<10%)	Low (10-25%)	Medium (25-50%)	High (50-75%)	Very high (>75%)
C3. Type of land use	Pipeline/FCDS, pads	road	-	-	-
C4. Type of protection facility	none	benching	Rubble masonry	-	-
C5. Drainage facility	none	-	Interceptor canal	-	-

*A- VERY HIGH , B- HIGH, C- MEDIUM, D- LOW, E- VERY LOW

Table 6. Criteria for Assessing Slope Instability based on Hydrogeology (modified after Lee and Juang,1992)

Secondary level Factor under hydrogeology	**Criteria for Evaluating Slopes**				
	A	**B**	**C**	**D**	**E**
D1. Seepage	Continuous flow	Occasional drops	Always damp	-	Dry
D2. Permeability of top soils	Low (clay)	Medium (silt)	High (sand)	-	-
D3. Presence of water course	Below (toe of slope)	Along side	-	-	None

*A- VERY HIGH , B- HIGH, C- MEDIUM, D- LOW, E- VERY LOW

Table 7. Slope Instability Ranking

RANKING	EXPLANATION
VERY HIGH INSTABILITY	ratings of A with EI +VI weights are dominant
HIGH	ratings of A with I weights + B with EI +VI weights are dominant
MEDIUM	ratings of B with I weights + C with EI + VI weights are dominant
LOW	ratings of C with I weights + D with EI + VI weights are dominant
VERY LOW	ratings of D with I weights + E with EI + VI weights are dominant

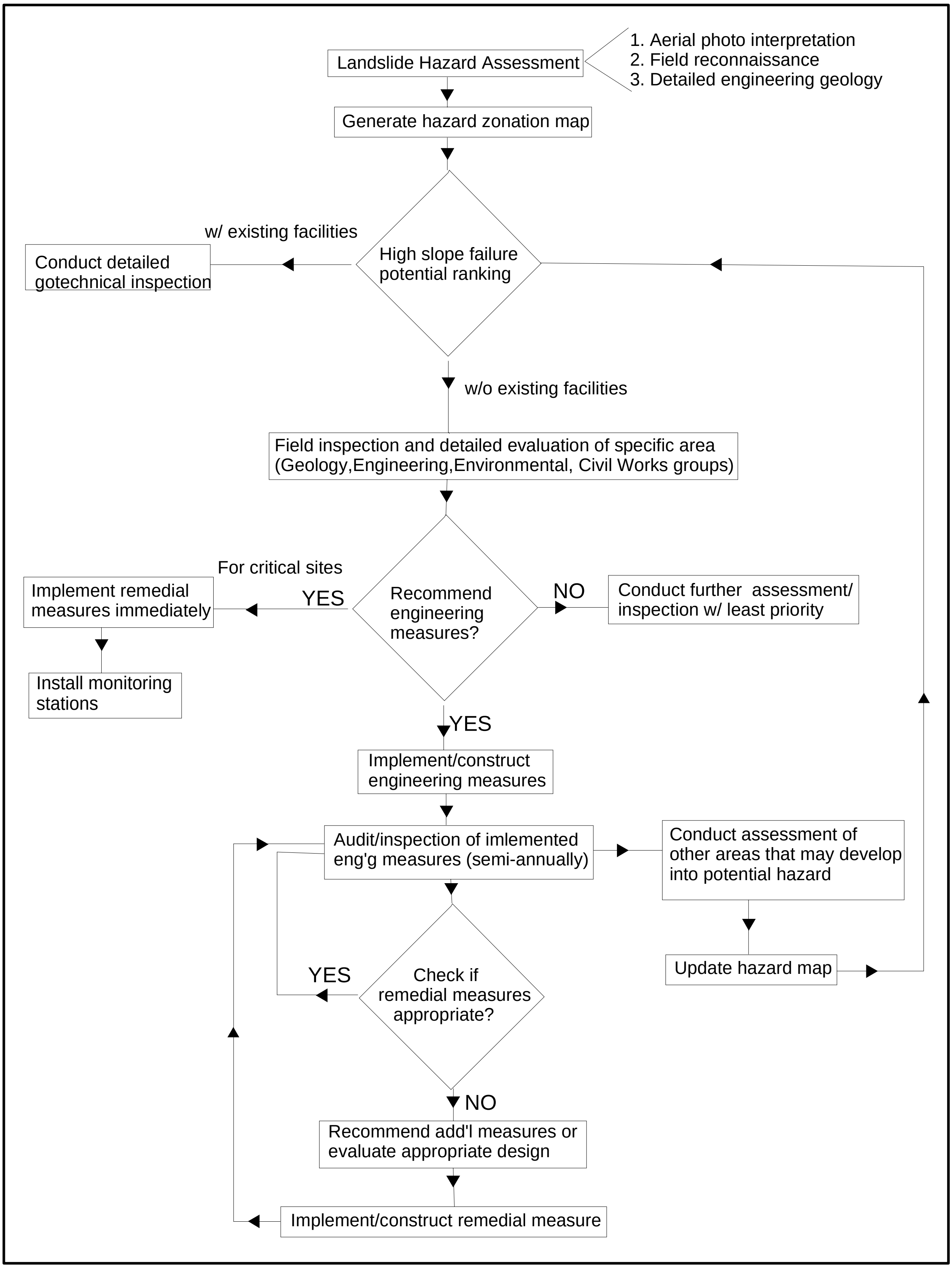

Figure 12: Flowchart summary of PNOC-EDC's activities in dealing with landslide hazards.