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Mitigating a Deep-Seated Landslide Hazard- the Case of 105 Mahiao Slide Area, Leyte Geothermal Production Field, Philippines

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ABSTRACT

The 105 Mahiao landslide area lies within the downthrown block of Mahiao Graben of the Leyte Geothermal Production Field (LGPF). The geologic feature is traversed by the Central Fault Line, a major bifurcate of the Philippine Fault that traverses the geothermal field.

Ground cracks and differential movements were recorded since 1996, after which engineering mitigating measures were implemented to avert the landslides which could potentially damage EDC geothermal facilities such as pipelines, injection wells, separator vessels, and also cause widespread flooding by damming of Mahiao River. Temporary road repairs, concrete lining of canals, refilling of cracks and construction of concreted reinforced masonry walls and benching were undertaken to reduce the potential massive landslide estimated at ~800,000 m^3.

In February 2006, coincident with the Guinsaugon landslide of Southern Leyte, ground bulges, massive cracks and other manifestations of ground deformation in 105 Mahiao led to re-evaluation of the area. To address the landslide hazard which could potentially cost EDC of approximately $87,000 per day in revenue loss from power outage alone, massive slope benching to remove 123,000 m^3 of mass and subsequent vegetative restoration program were instituted. Further geotechnical investigations were also conducted and water-level monitoring wells were installed in the area to continuously monitor the effectiveness of the new mitigating measures. No new cracks, bulges and manifestations of ground movements were documented to date, attesting to the effectiveness of the mitigating measures implemented.

1. INTRODUCTION

The 105 Mahiao slide area is situated 400m southwest of 105 pad in Mahiao sector of the Leyte Geothermal Production Field (LGPF), Philippines (Fig. 1). It lies within the downthrown block of the Mahiao Graben which is traversed by the Central Fault Line, a major bifurcating segment of the Philippine Fault prominent in the Leyte geothermal field (Fig. 2; Delfin, et al., 1995 in Leynes et al., 2002). The topography in Leyte field is rugged and mountainous while the climate has no pronounced maximum rainy period and no dry season based on the climate map of the Philippines (Fig. 3).

1.1 Background of 105 Mahiao slide

Vertical displacements of about 30cm. at the top of the former quarry site in the 105 slide area were first observed in 1996 after continuous heavy rainfall, so that quarrying operations were ordered stopped. New cracks however appeared three years after and landslides occurred along the slopes above the upper road after a typhoon in 2000 and 2001 (Figs. 4 and 5). Selective benching was then undertaken to arrest the slides with installation of concrete-lined canals and masonry walls at the toe. However, coincident with the Guinsaugon landslide last February 2006, bulges at the toe, massive re-activated cracks near the crown (~300m length; ~500m above the toe), small slides along the slopes as well as cracks on the bedrock and masonry walls at the toe prompted a re-evaluation of the area, and subsequently construction of corresponding mitigating measures to avert the landslide risks involved (Herras and Caranto, 1996; Leynes, 1999; Leynes, 2000; Pioquinto and Leynes, 2001; Pioquinto, 2006).

The objective of this paper is to present the nature and mechanisms involved in the 105 Mahiao landslide, the probable impacts of such landslide magnitude if left unaddressed and the remedial measures undertaken to mitigate the landslide hazard.

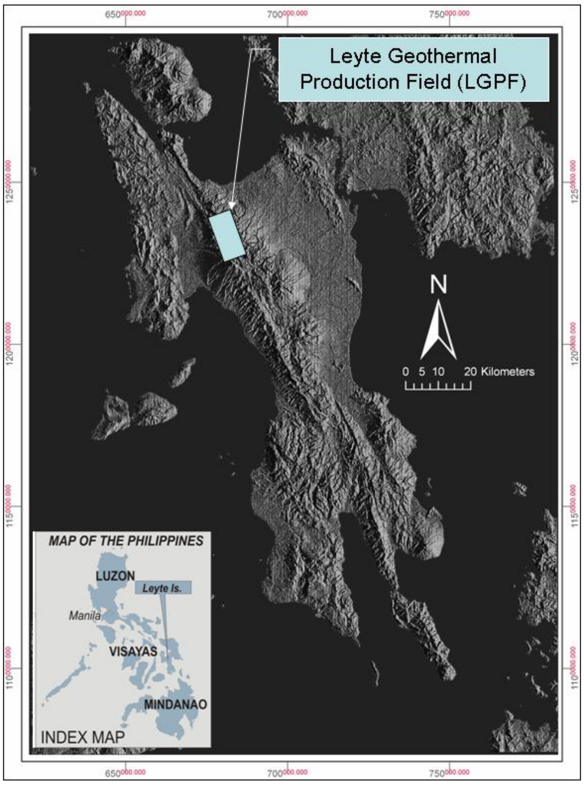

Figure 1. Location map of the Leyte Geothermal Production Field in Leyte Island, Philippines

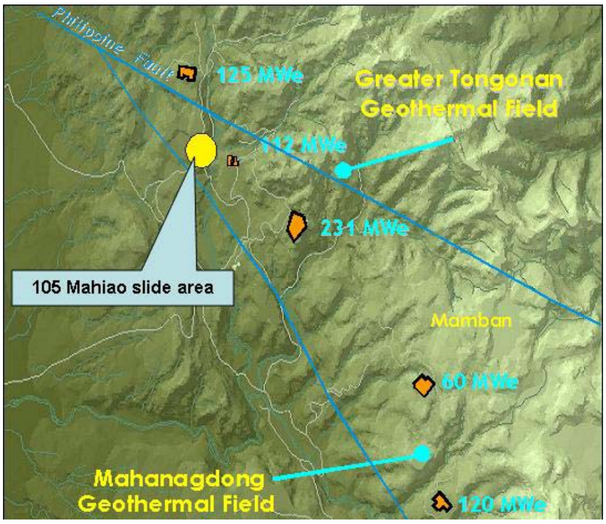

Figure 2. Location of 105 Mahiao slide area relative to the Philippine Fault.

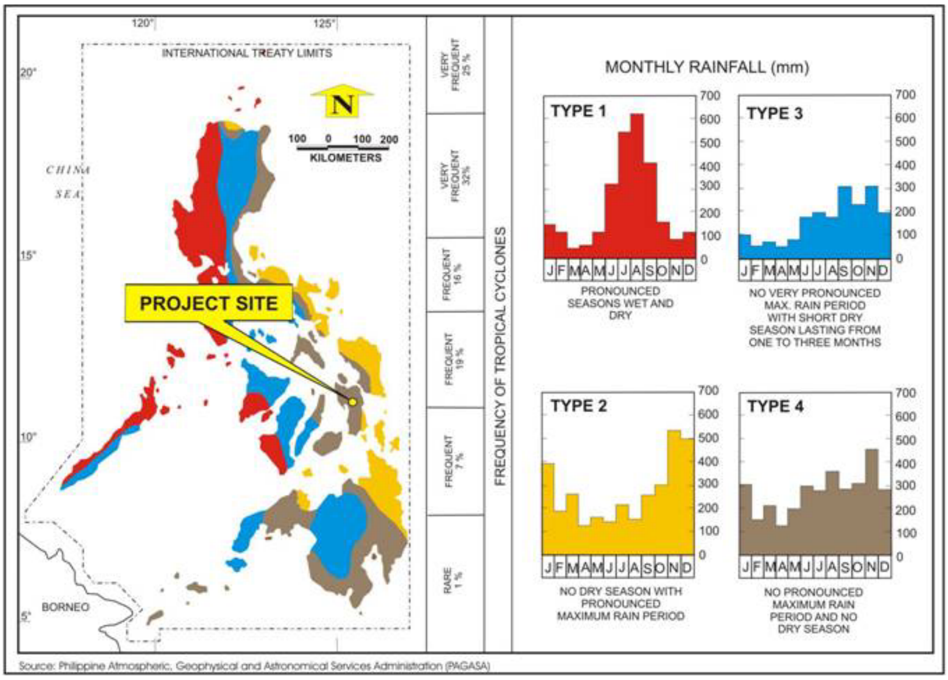

Figure 3. Climate map of the Philippines showing location of the Leyte project site.

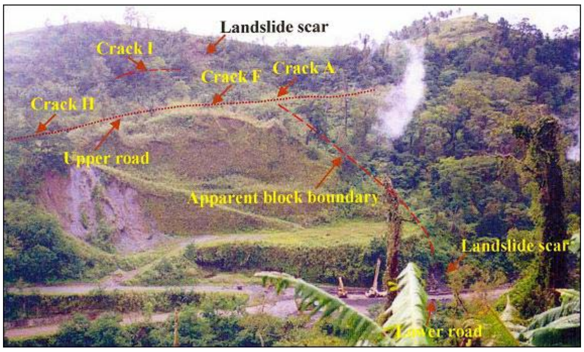

Figure 4. Photo taken last 2000 showing slides in the area after heavy rains.

Figure 5. Photo taken last 2001 showing minor benching undertaken to address the landslides after Typhoon Auring.

2. NATURE OF LANDSLIDE AND MECHANISMS INVOLVED

2.1 Landslide Nature

The lithology in the area is composed of andesite volcanics and tuff breccias. The 105 vicinity is veneered predominantly by sandy tuff and coarse-grained pyroclastics with some boulders of andesitic volcanics embedded in some portions in the upper slopes. In the lower slopes or along the toe, outcrops of tuff breccias are observed with clayey to sandy layers exposed at the base wherein groundwater seepage is manifested. Local faults are also present in the vicinity and are shown in Figure 6.

Mass movement in the 105 Mahiao vicinity was evident due to the presence of upheaves or bulges observed in the lower road along the inner portion of the road (Fig. 7). A huge boulder with obvious cracks and detached slabs was also seen just beside the road posing risks to traffic (Fig. 8). Meanwhile, in the upper road, cracks were noticed perpendicular as well as oblique to the road with some recent slide scars (Figs. 9 and 10). Tension cracks mapped as early as year 2000 were already present upslope of the upper road so that the rains could have aggravated the situation as these present cracks emanated. Moreover, some recent microfault displacements were also observed on rock outcrops just above the lower road (Fig. 11) and rock samples reveal a fault- brecciated nature of the tuff breccias present at the base of the slide (Fig. 12; Rossel, 2006).

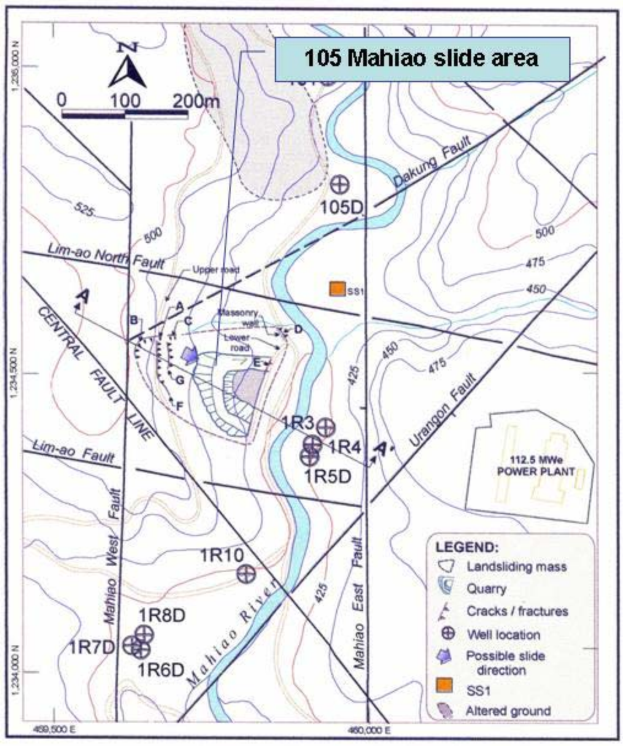

Figure 6. Structural map showing local faults in the vicinity of 105 Mahiao slide.

Figure 7. Pressure heaves or bulges found at the lower road which appeared at the same time when cracks were observed at the upper road after a period of continuous rains in the project site.

Figure 8. Cracks noted within the bedrock at the base of the slide.

Figure 9. Photo shows cracks along the upper road within the slide area.

Figure 10. Smaller slide scars noted beside those cracks along the upper road.

Figure 11. Photo shows recent microfault displacement on a bedrock near the base of the slide.

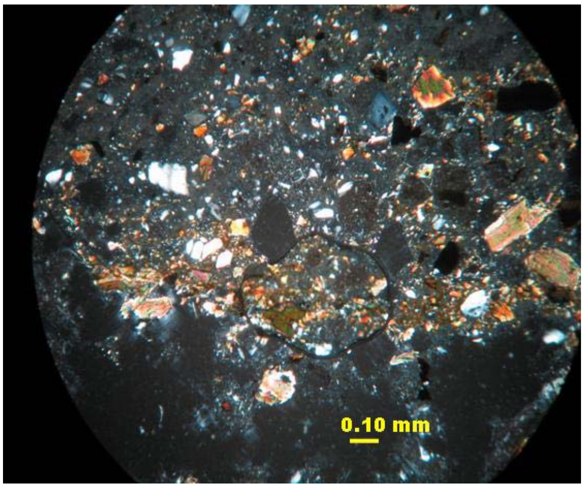

Figure 12. Thin section photo of a rock sample showing a fault-brecciated nature of bedrock at the base of the slide.

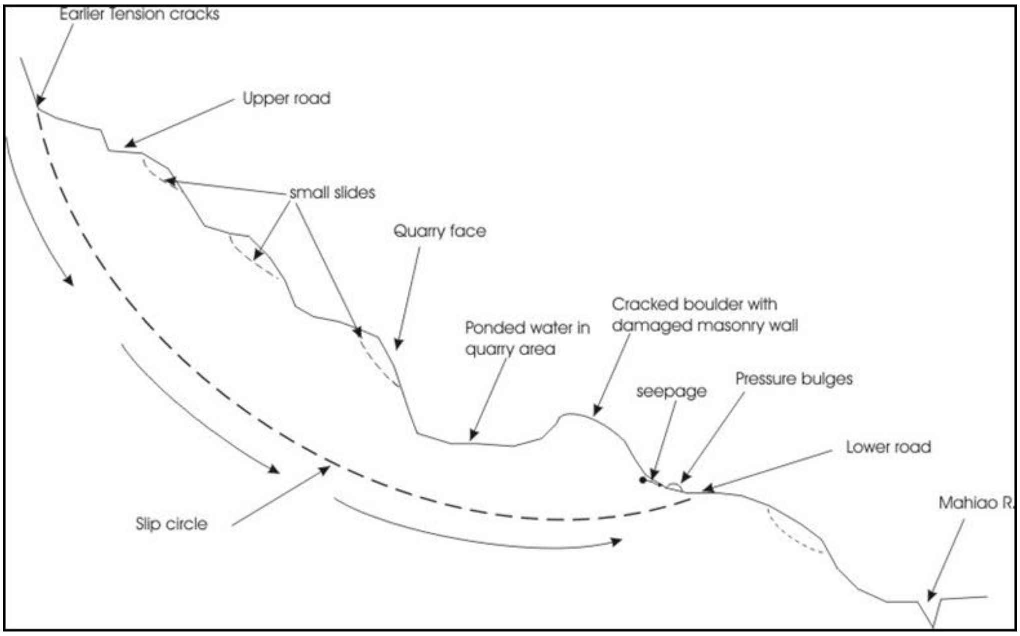

Figure 13. Schematic profile of the 105 Mahiao slide area. (Note: not drawn to scale)

Based on the above observations and recent data, the 105 Mahiao slide is possibly an ancient reactivated slide with a huge block movement of rotational type. It has a big slip circle with smaller slips within where the tension cracks upslope of the upper road may represent the crown or top portion of a huge mass movement downslope. The toe of this slide could be the portion along the lower road indicated by the pressure heaves or bulges. The schematic profile of the 105 Mahiao slide is illustrated in Figure 13.

2.2 Landslide Mechanisms

Several factors that could have induced the movements in the 105 vicinity include rainfall/seepage, unconsolidated slope material of low cohesion, steep slope geometry and probable active tectonic stresses present in the vicinity.

Past records show that unusually heavy and continuous rainfall events occur in the early weeks of the month of February in the Leyte Geothermal Production Field (LGPF) so that slides and floodings are not uncommon. Since the existing slopes of 50°-70° is predominant in the 105 area, the action of run-off and seepage greatly undermines the internal cohesion of the surficial materials which consists mostly of clast-supported sandy tuff and easily-eroded pyroclastic materials. In addition, percolating groundwater may have seeped through the deep-seated fractures and tension cracks in the bedrock where faulting and brecciation is also present due to active tectonic movements associated with the Philippine Fault. Uniform movement of the whole face of the slide area at an apparent displacement rate of 5mm per month was also established using electronic distance measurement (EDM) (Seastres and Herras, 2000; Caranto and Jara, 2006; Pioquinto, 2006; Zarco, 2006).

3. LANDSLIDE IMPACT

The sliding mass in the 105 Mahiao vicinity is approximately 800,000 cubic meters. At a very rapid movement, such volume is large enough to obliterate the injection pad with 3 injection wells downstream (Fig. 14). In addition, spillage of slide materials can create damming of the Mahiao River just below the slide area. Such damming may probably flood the separator station located about 300m upstream from the injection pad (Fig. 15). Not including the physical damage costs of separator station and reinjection wells, power plant generation outage alone may translate to a revenue loss of around 87,000 USD per day.

The above scenario presented necessitated urgent actions in order to address the risks associated with the 105 Mahiao landslide.

4. MITIGATING MEASURES

In view of the huge risks involved, engineering mitigating measures were implemented in the 105 Mahiao slide area. These are the following: (1) construction of concrete-lined interceptor canals both parallel and longitudinal to the slope contours (Fig. 16); (2) construction of masonry walls with weep holes and horizontal cross drains at the base or toe of the slide; (3) regrading or benching of slopes at appropriate intervals and gradient (~1.4H:1V) (Fig. 17); and (4) revegetation.

The installation of concrete-lined drainage system and vegetative restoration were designed to minimize groundwater seepage and increase shear strength property of the slope materials. Seepage should be effectively addressed because it creates additional load within the slide mass and creates pore water pressure which is detrimental to soil cohesiveness. If soil cohesion is reduced due to seepage, slide will eventually happen. Plant roots help hold the soil materials together thus minimizing the effect of pore water pressure.

The rationale of the benching operation was to unload some mass at the upslope portion to the downslope portion at applicable factor of safety. If mass is transferred from higher to lower parts, you could effectively decrease the acceleration of the slide thus decreasing its momentum to move at farther distance. Movement could even be hampered because of a lesser force generated by a reduced load. The less distance traveled by a mass movement contributes to lesser momentum thus lowering the associated risks. During the benching operation approximately 123,000 cubic meters of overburden materials were removed in the upper slopes or near the crown of the slide area.

After implementing the above remedial measures, in-depth geotechnical investigation was still conducted in order to determine whether those remedial measures were effective enough in addressing the landslide hazard. Boreholes were drilled and test pits were excavated for slope stability studies and calculation of adequate factors of safety. Some of the boreholes served also as groundwater level monitoring wells in which water level measurements were presently being done on a periodic basis depending on the weather season within the project site.

To date, there are no recorded or observed evidences of movement or ground deformation in the vicinity, even after earthquakes and typhoons that had transpired attesting to the effective stabilization of the 105 Mahiao landslide (Fig. 18).

5. SUMMARY AND CONCLUSIONS

The 105 Mahiao landslide study area is located within the down-faulted block of the Mahiao Graben which is traversed by a segment of the Philippine Fault that traverses the Leyte geothermal field.

Initial studies since 1996 noted ground cracks and differential movements in the area in which mitigating measures were implemented to avert the landslides which could potentially bury EDC geothermal facilities such as pipelines and injection wells as well as damage nearby separator vessels and eventual power plant shutdown due to possible damming of the Mahiao river below the toe of the slide. Periodic downsliding and significant ground deformations again manifested after incessant rains brought about by typhoons in years 2000 and 2001. Temporary road repairs, concrete lining of canals, refilling of cracks, construction of reinforced masonry walls and benching in selected areas were undertaken to reduce the potential landslide mass estimated at ~800,000 m3. Continuous monitoring of the area was included as part of the field-wide landslide risk evaluation and mitigation program of the company in which an apparent displacement rate of 5mm/month was established using electronic distance measurement (EDM) method.

Figure 14. Photo of RI pad which is directly along the path of the 105 Mahiao landslide (viewed from the upper road).

Figure 16. Photo showing concrete-lined ditches designed to address surface run-off in the slide area.

Figure 15. Photo showing the separator station located 300m upstream of Mahiao River from the RI pad that will be directly affected by the 105 Mahiao landslide (viewed from the lower road).

Figure 17. Photo showing slope modification implemented at the 105 Mahiao slide area.

Figure 18. This is the photo of the 105 Mahiao landslide area taken after almost a year after all mitigating measures were implemented.

In February 2006, ground bulges, massive cracks and other manifestations of ground deformation re-appeared after an extreme rainfall. Massive slope benching to remove additional 123,000 m3 of potential landslide mass was then implemented. Vegetative restoration and installation of concrete-lined canals were also completed. A geotechnical investigation conducted after the benching operation indicated that the slope is already stable. Water-level monitoring wells were also installed within the slope as part of monitoring program. Subsequent earthquakes and typhoons have not induced further mass movements along the slope implying effective mitigation of the 105 Mahiao landslide.

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