Evaluation of the Kundasang Ground Movement based on Geological, Geotechnical Investigations and Stability Modelling

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Abstract. Kundasang is located in a geohazard zone that consists of two active major regional faults and weak geomaterials with highly weathered, jointed and fractured rock. The existence of active faults are considered as one of the factors which influence the occurrence of large ground movement in the Kundasang area. Kg Lembah Permai which is located adjacent to the Kundasang town is one of the critical affected areas by progressively ground movement that had caused significant destruction to the permanent structures and infrastructures that lead to economic loss to the government and residents, respectively. This paper describes past and new data, and also the outcomes that have been integrated to redefine and update the ground instability mechanism in Kg Lembah Permai. Two new approaches of mapping have been applied. The first is remote mapping which involved detection and interpretation of local faults using Digital Terrain Model (DTM) derived from Lidar image. The second is on-site mapping of geodynamic features in the field using 3D approach. Results showed that most of the destruction exhibited towards +Y and -Z direction which represent the movement towards northeast and vertical downward respectively. From landslide modelling, the rate of displacement, geometry of the sliding surface and the current stability condition of the landslide can be quantified. It is expected that with detailed and comprehensive knowledge, a suitable design of geotechnical solution at difficult ground can be conducted accurately and objectively which eventually could promote sustainable development and enhancing public safety in the Kundasang area.

Keywords: Failure mechanism; geodynamic features; geohazard; ground movement; sustainable development

1. Introduction

Previous study revealed that Kundasang is located in a geohazard zone due to the presence of numerous mass movement, localised failures and ground creeping at various locations. This problem has caused damages to properties such as building structures, roads, telecommunication towers, electricity infrastructures and agriculture orchards which directly result in high economic losses to the government, investors and residents in Kundasang. Kundasang is located in a geohazard zone that consists of complex geological structures involving intersection of two major active faults and composed of weak geomaterials with highly jointed and fractured rock [1] and [2]. These are among the major factors identified that greatly contributed to the ground movement occurrences in the Kundasang area.
Seismic activity refers to local earthquake occurrence and appears to be related to the existence of two major active faults. These major active faults namely, the Mensaban and the Lobou-Lobou Faults, were identified as the most likely cause of the local earthquakes in the area [3]. Therefore, it is believed that apart from rainfall, earthquake is also identified as one of the triggering factors for ground instability occurrences in Kundasang. In fact, many other factors could also contribute to ground instability problem in Kundasang such as tectonic, lithology, climate, geomorphology processes and human activities.

Kg Lembah Permai which is located in Kundasang town is one of the critically affected area by the progressively ground movement. Although the movement is imperceptibly slow, it had continued to create significant destruction to permanent structures and infrastructures that lead to economic loss to the government and residents respectively. In research pertaining to ground movement, it is important to understand the fundamental of the failure mechanism and factors that triggered the hazard. This paper discusses previous and new data that have been integrated to redefine and update the ground movement information in Kg Lembah Permai.

Two new approaches of mapping had been applied. First is remote mapping which involved identification of sign of ground movement and interpretation using Digital Terrain Model (DTM) derived from Lidar image. Second is on-site mapping of geodynamic features in the field using 3D approach. Both the new approaches of mapping that are expected could improve and enhance previous mapping outcomes. From landslide modelling, the rate of displacement, geometry of the sliding surface and the current stability condition of the landslide can be quantified. It is expected that with detailed and comprehensive knowledge, suitable design of geotechnical solution at difficult ground can be conducted accurately and objectively which eventually could promote sustainable development and enhancing public safety in the Kundasang area particularly Kg Lembah Permai. This study contributes to the understanding of the mechanics of ground movement in Kg Lembah Permai which is a step forward for landslide vulnerability and risk analysis in Malaysia.

2. Geology
The local geology of the Kundasang area is mainly underlain by meta-sedimentary rock of the argillaceous Trusmadi Formation (Palaeocene to Eocene age), the sedimentary rock of the arenaceous Crocker Formation (Late Eocene to Early Miocene age), the Pinosuk Gravels and the Quaternary Alluvium Deposits [4]. Kg.Lembah Permai is underlain by the Trusmadi Formation which consist of phyllite, slate, meta-greywack, sandstone and shale [5]. The rock types of Trusmadi Formation mainly consist of dark grey shale/mudstone with subordinate siltstone, sandstone and volcanics. Some of the Trusmadi Formation rocks have been metamorphosed to low grade of the green schist facies; the sediment has transformed into slate, phyllite and metarenite [6]. Rocks in Trusmadi Formation are strongly folded, faulted and fractured. The rock generally exhibits semi foliated slaty cleavages and contains clasts or blocks of sandstone, siltstone and carbonaceous shale of various sizes. [7] suggested that these blocks, which are sub angular to sub rounded, represent sandstone beds within the argillaceous sequence, which have been intensively deformed. The deformation of the Trusmadi Formation and its argillaceous condition lead to the condition which is susceptible to instability such as landslide and erosion.

The terrain of the entire Kundasang area is generally undulating. Some slopes are very steep while others are gentle or even flat. Geomorphology of Kg Lembah Permai is composed of very gentle slope which extent from southwest to northeast. The highest point at 1,270m is in the southern part, and the lowest, 1100m above mean sea level is in the northeastern part. The main drainage system at Kg Lembah Permai is Sungai Liwagu which is located at the northern part of the area. The river valley of Sungai Liwagu at the Kg Lembah Permai has narrow valley floors and steep escarpments. This is probably due to the argillaceous behaviour and less resistant rock types that formed the Trusmadi Formation.
3. Large scale ground movement

Based on mapping using DTM and field survey, a large extent of ground movement occurrence was detected at Kg Lembah Permai area. This can be observed through numerous presences of geodynamic features at certain locations within the Kg Lembah Permai area. According to [2], the whole Kg Lembah Permai is represented by one large scale landslide system which is known as K1. In this study, terminology of large scale landslide system K1 has been changed to large scale ground movement K1 to describe the presence of large scale progressive ground movement in Kg.Lembah Permai area. Terminology of ground movement is used because most of locations affected within Kg Lembah Permai are situated at the gentle terrain. Thus, the clear features of landslide are less visible and not clearly observed at the field. Some improvement has been made in term of landslide system boundary from the latest mapping work conducted within the vicinity of Kg Lembah Permai. The latest ground movement K1 boundary is shown in Figure 1.

From field observation, most of the rock formations that exist at Kg Lembah Permai are extremely weathered and transformed to soil. This is due to the past complex history of tectonic activity, lithology and geomorphological processes in this area. According to the proposed new version of the Varnes Classification System [8], the type of movement in Kg.Lembah Permai can be classified as Slope Deformation which specified as Soil Creep (Table 1). Previous and current observation of ground movement at Kg.Lembah Permai area have proven that very slow rate of progressive ground movement had occured. Although the actual rate of movement in the field is not measured in this study, the effect from the ground movement still can be observed through the presence of geodynamic features or failures at buildings, infrastructures and slopes. Based on field monitoring conducted by [9], K1 Landslide Complex experienced horizontal movement of an average approximately 98mm per year in northerly direction. Therefore, based on landslide velocity scale (Table 2), the rate of ground movement in Kg Lembah Permai can be concluded as very slow [8]. This can be observed through regular maintenance work of house structures defect due to the ground movement.

![Figure 1. The latest ground movement K1 boundary (red dotted line).](image-url)
Table 1. Partially summary from proposed new version of the Varnes classification [8]

| Type of movement | Rock                          | Soil                          |
|------------------|-------------------------------|-------------------------------|
|                  | Mountain slope deformation    | Soil slope deformation        |
|                  | Rock slope deformation        | Soil creep                   |
|                  |                               | Solifluction                 |

Table 2. Landslide velocity scale (WP/WLI 1995 and Cruden and Varnes 1996)[8].

| Velocity class | Description     | Velocity (mm/s) | Typical velocity | Response    |
|----------------|-----------------|-----------------|------------------|-------------|
| 7              | Extremely rapid | 5 x 10³         | 5 m/s            | Nil         |
| 6              | Very rapid      | 5 x 10¹         | 3 m/min          | Nil         |
| 5              | Rapid           | 5 x 10¹         | 1.8 m/h          | Evacuation  |
| 4              | Moderate        | 5 x 10³         | 13 m/month       | Evacuation  |
| 3              | Slow            | 5 x 10⁵         | 1.6 m/year       | Maintenance |
| 2              | Very slow       | 5 x 10⁷         | 16 mm/year       | Maintenance |
| 1              | Extremely slow  | 5 x 10³         | 5 m/s            | Nil         |

4. Remote and geodynamic feature mapping

Based on interpretation from Digital Terrain Model (DTM) which generated from Light Detection and Ranging (Lidar) image, two main local faults have been detected within Kg. Lembah Permai area. These faults are oriented NE-SW and WSW-ENE respectively (figure 2). From DTM it clearly showed that the NE-SW fault which striked approximately at the middle of Kg. Lembah Permai has cut the WSW-ENE fault. The WSW-ENE fault has been separated and displaced by the NE-SW fault.

Figure 2. Two local faults detected from DTM at Kg. Lembah Permai
Based on the previous information which was observed and inferred from aerial photographs, it clearly showed that there were existence of faults at the Kg.Lembah Permai area. The orientation of faults is approximately similar with faults detected through DTM. According to [1], Lobou-Lobou Fault which oriented N200E in Kg.Lembah Permai has cut and displaced a narrow tarred road left-laterally. This displacement is shown by offset of the white central line. Based on field mapping that was conducted at the road stretch not far from a displaced tarred road, it can clearly be observed that tension cracks have developed across the road with orientation N200E (Figure3). The presence of tension cracks across the road can most likely be related with the effect from Lobou-Lobou Fault due to similar orientation. The NE-SW fault that is interpreted from DTM most likely also can be considered as part of Lobou-Lobou Fault which is a northern segment of the Crocker Fault Zone [1]. According to [10], Lobou-Lobou Fault Zone that related to the earthquake that occurred on 5th June 2015 in Kundasang area is oriented NE-SW. Therefore, both faults at Kg. Lembah Permai which was clearly detected through DTM are most likely located and associated within Lobou-Lobou Fault Zone.

In general the ground movement that occurred at Kg.Lembah Permai has affected several building structures, infrastructures such as road, drain, electric posts and also existing slopes. In relation with the mechanics of ground movement, it is compulsory to map failures element or geodynamic features that was caused by the movement. Hence, all geodynamic features that existed in the field are mapped using 3D approach where all failures that had been identified were marked as X, Y and Z direction. X direction represent East-West (EW), Y direction North-South (NS) and Z direction represent vertical movement or displacement. Results from geodynamic features mapping exhibited that most of the failures are in +Y (north) and –Z (vertical downward) direction. The +Y direction shown by the movement is not exactly towards north but it is more towards northeast direction. Geodynamic features mapping in the field also showed that most of the affected structures are located on the right part of NE-SW fault especially at the valley area. Further towards east, failures also detected at the main road with the presence of tension cracks and old scar at the slope next to the War Memorial. Towards west direction, only a few of failures are detected which shown by small cracks on the slab. Generally, the ground movement striking at 3000 with dip angle lesser than 100 and dip direction towards 0200.

5. Modelling of ground movement
Ground movement modelling has been carried out using the finite element program Plaxis 2D version 8.5 for determining the rate of movement, failure mechanism and evaluating the stability of natural large ground movement system, K1. The cross-section AA’ which utilized for modelling is presented in Figure 4.
Due to the unavailability of boreholes data within this location, the construction of the subprofile for modelling is based on the interpretation of previous resistivity investigation which was conducted by Minerals and Geoscience Department Malaysia (JMG) in 2011 [11]. The interpretation of resistivity data revealed that two non-horizontal layers of geomaterial exist within the large ground movement system, K1 which were dipping towards north direction. Resistivity results also showed that the presence of faults in Kg.Lembah Permai where the value of resistivity obtained were low and extended to further depth (Figure 5). Previous study by [6] which is related to the geology of Trusmadi Formation at adjacent to the study area had determined that the most dominant geomaterial of the Trusmadi Formation consist of Sub-Phyllite and Slate. Since the entire area of Kg Lembah Permai is underlain by Trusmadi Formation, it is assumed that the geologic behaviour of geomaterial is similar to the adjacent area. Therefore, for the purpose of modelling, parameters from the previous analysis possibly can be considered to represent the physical and engineering properties of geomaterial in Kg Lembah Permai. According to [6], the failure material of Trusmadi Formation was classified as poorly graded of silty clay. Detailed results from laboratory test conducted by [6] is presented in Table 3.
In order to represent the actual behaviour of soil materials, analysis using finite-element methods requires the application of a non-linear model [12]. The hyperbolic model is one of the most frequently used non-linear model for predicting the behaviour of soils [12]. Thus, in this study, an elastoplastic type of hyperbolic model known as Hardening Soil Model has been selected to simulate the behaviour of soil. According to [13], all soils whether it is fine-grained or granular will exhibit curve-linear failure envelope with zero cohesion. Hence, in this landslide modelling, the small value of cohesion which is close to zero is utilized. Detailed parameters used for modelling is shown in Table 3. In order to determine the rate of landslide movement, plastic calculation is carried out with time interval of 365 days. The result showed that the maximum rate of horizontal displacement is 120 mm/year (Figure 6). After plastic calculation, a stability analysis is executed by reducing the strength parameters of the soil. For this purpose, the type of calculation involved is Phi-c reduction. In stability analysis, failure mechanism of the large ground movement system, K1 is developed as shown in Figure 7. As shown in the model, the depth of slip plane is approximately 60m from the ground surface and it is extended until the toe of the slope. Once the failure mechanism is developed, the factor of safety is automatically calculated. The factor of safety is represented by $\sum M_{sf}$ which showed the value of 1.027 (Figure 8).

**Table 3.** Properties of geomaterial tested by [6] which used for modelling

| Properties                      | Sub-Phyllite | State |
|--------------------------------|--------------|-------|
| Unit Weight (kN/m$^3$)         |              |       |
| $\gamma_{\text{unsat}}$        | 18           | 22    |
| $\gamma_{\text{sat}}$          | 21           | 24    |
| Permeability (m/day)           | 7.057        | 3.296 |
| Stiffness Modulus (kN/m$^2$)   |              |       |
| $E_{50}\text{ ref}$            | 5000         | 120000|
| $E_{\text{oed ref}}$            | 5000         | 116000|
| $E_{\text{ur ref}}$            | 15000        | 240000|
| Cohesion, C (kN/m$^2$)         | 0.1          | 0.1   |
| Angle of Friction, $\phi$ ($^0$) | 7.96        | 24.1  |
| Poisson’s ratio, $V_{\text{ur}}$ | 0.4         | 0.3   |

**Figure 6.** Plastic calculation shows the maximum rate of horizontal displacement is 120mm/year
Discussion and conclusion

The presence of strongly folded, faulted, highly fractured and jointed rock in the Trusmadi Formation indicates that the formation had undergone long history of complex tectonic activities in the past. These local discontinuities structures might influence the physical and mechanical properties of the rock in the formation. Highly intensive of faulting and folding together with high degree of fracturing and jointing will accelerate the weathering process by providing sufficient passages for water infiltration. Basically, weathered rock materials are considered very weak material due to high porosity and high pore-water pressures that generated by groundwater. Thus, it could lead to the ground failure such as ground movement.

The existence of heterogenous lithological units in the Trusmadi Formation might also influenced the ground stability in Kg Lembah Permai area. Different lithological units will exhibit different characteristic and strength. For examples, the interbedded sandstone shale and sandstone-slate-phyllite contacts are prone to allow water flow which may weaken the shale surface that could lead to failure within the entire formation [6]. Although the massive sandstone layer is comparatively stronger than other layers, mass failure is still possible to occur due to the existence of sliding surface contributed by shale layer especially in wet condition. The sliding surface formed by reaction of shale and water has become more effective with the increase of rock bedding plane angle.
Interpretation from Digital Terrain Model (DTM) has revealed that two main local faults exist within Kg. Lembah Permai area with orientation NE-SW and WSW-ENE respectively. Previous resistivity investigation also showed that somewhere in the middle of Kg Lembah Permai there was a presence of a very deep layer with very low resistivity value which can be interpreted as fault. The presence of fault in Kg Lembah Permai will provide sufficient passage for water infiltration. This condition could trigger weathering process to occur within this area. Resistivity data also showed that the substrata at Kg Lembah Permai is in a saturated state with a very shallow water table. The saturated area is located at the right part of NE-SW fault. This condition might contribute to ground movement occurrence at the right part of the NE-SW fault in Kg Lembah Permai.

Geological factors such as history of tectonic activities, existing properties of geomaterial, ground water and existing faults are most likely identified as major contributor to large ground movement in Kg Lembah Permai. It is not deniable that rainfall and earthquake are the main triggering factor for ground movement occurrence in Kg Lembah Permai. The type of movement in Kg. Lembah Permai can be classified as Slope Deformation which composed of Rock Slope Deformation and Soil Creep. Result from ground movement modelling showed that the maximum rate of horizontal displacement in Kg Lembah Permai is 120 mm/year. This value is slightly higher than the value from the monitoring conducted by [9] which showed average approximately 98mm/year in northerly direction. Both values conclude that rate of ground movement in a natural condition at Kg Lembah Permai as very slow. In stability analysis, failure mechanism of the large ground movement system, K1 is developed. The depth of slip plane is approximately 60m from the ground surface and it is extended until at the toe of the slope. The factor of safety calculated from ground movement modelling showed the value of 1.027. It is expected that with detailed and comprehensive knowledge, a suitable design of geotechnical solution at a problem ground can be conducted accurately and objectively which eventually could promote sustainable development and enhancing public safety in the Kundasang area.

7. References
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