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Seismic Refraction Investigation on Near Surface Landslides at the Kundasang area in Sabah, Malaysia

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Abstract

Surface geophysical method was used in studying the effect of natural disaster impact and subsurface physical changes located in an active geohazard zone at the Kundasang area in Sabah, Malaysia. The natural disaster impact was a previous surface and subsurface ground damage caused by a landslides activity, and the consequent civil engineering infrastructure failure. 2D seismic refraction tomography (2DSRT) was used in evaluating the continuous subsurface ground damage with particular reference to geomaterials and landslide features based on compressional wave (Primary velocity, v_p) results. A total of four spread lines were conducted in two different zones (Northeast and Southwest zone) in Kundasang Secondary School (SMK Kundasang). Primary velocity data was acquired and recorded using ABEM Terraloc MK6 seismograph with the seismic wave being triggered by an impact and detected by arrays of sensitive devices called geophones. 2D seismic refraction primary velocity results representing subsurface profile for each survey line were calculated to determine time and depth of the subsurface profile investigated based on linear and delay time analysis supplied by Optim software package and supported by previous borehole data. The seismic refraction method identified three main layers of geomaterials which contained a subsurface landslides anomaly within the layers. The results consist of top soil/residual soil (330 – 600 m/s) 0 – 6 m, weathered zone with a mixture of soil, boulder and rock fractured (500 – 1900 m/s) 2 – 25 m and fresh rock/bedrock (> 2300 m/s) from 8 m depth. The landslides geometry was determined inconsistently within the survey line from 3 – 25 m (thickness), 57 and 75 m (width) and 100 m and more (length) with a primary velocity of 700 – 1800 m/s. The seismic refraction profiles obtained also revealed that the landslide occurrence extends from the southeast zone and continuously heading towards the northeast zone. A good matching seismic refraction results was obtained and calibrated using borehole results which shows that this technique was appropriate to be applied in near-surface landslide assessment which can further substantiates and compliments borehole data and others physical mapping

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data rapidly in a lower cost. Furthermore, this geophysical method adopts a surface technique that can minimise the disruption and damage to the site thus preserving a sustainable environment during the site investigation data acquisition stages.

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Keywords: ground damage; landslide ; 2-D seismic refraction method ; primary velocity

1. Introduction

Natural disaster has always been a major threat due to its unpredictable occurrence. It is often a consequence of the earth's natural hazard such as earthquakes and volcanic activity, tsunami, flood, hurricane, landslides, etc. In geotechnical engineering, landslides have been established as one of a major natural disaster which creates a problem to the civil engineers and related parties since it causes considerable loss of property, life and the environment. Natural disaster caused by landslides has resulted in large losses involving properties and human life [1], [2], [3] and [4]. According to [1], landslides can occur due to intense rainfall, seismicity, water level change, storm wave or rapid stream erosion and human activity involving deforestation and infrastructure development in unstable slope areas. In Malaysia, most of the critical landslides event have occurred in the hilly areas and were basically triggered by a rainstorm, weathering of geomaterials, human activity or a weak seismological event. Several notable places of this type of event were located in Klang Valley (Bukit Antarabangsa, Hulu Langat and North Klang Valley Expressway areas), Perak to Pahang (Pos Slim to Cameron Highland areas) and Sabah (Kundasang areas).

Of the landslides areas mentioned above, Kundasang has been recognized as an active major landslides area due to an ongoing movement such as ground tension crack, sudden localized failure and ground creep. This problem has caused damaged and defects to properties such as building structure and pavement. Furthermore, it is a potential threat to human lives, which make their abode in this risky area. As reported by [5], Kundasang has registered an average of 0.5 meter translation soil movement per year and about 70 percent of the 50 square kilometres surrounding Kundasang Town has been identified as a high-risk area. They also reported that 22 houses and some of the chalets were damaged with progressive landslides that occurred in April 2011. According to [6] and [7], Kundasang area is located in geohazard zone consist of complex geological structure involving chaotic geomaterials with highly jointed rock, fault in a zone of intense seismic activity.

Several researchers, such as [7] have conducted studies in the Kundasang area using localized drilling method and geodynamic mapping while [6] has conducted a regional geological structure mapping based on fault zone intersection. Based on [7], the landslides occurred in a large scale and it is difficult to identify its critical boundary zone in the field. Hence, they mapped the geodynamic features (scarp, tension crack, seepage, ponding, bulging, systematic and displacement crack, structure damage and other physical properties) using physical mapping and drilling method (borehole). The application of drilling method was a good technique but it required many drilling points for better information which increased the cost and time of the investigation. Both cost and time for a borehole investigation is linearly dependent on the number of the borehole being drilled. A furthermore limitation on the technique is in that the drilling information will represents only a single - point information (1D) in the lateral space of the actual drilling location. Thus the interpolation between borings to assess the ground conditions will perhaps involve some degree of uncertainty especially in complex geological area [8], [9] and [10]. The application of geodynamic mapping and geological structure mapping also poses some limitation due to

surface information which basically being determined by a visible observation survey based on existing damaged features caused by a movement and outcrop of rock. This method produced surface information which was unable to extend the subsurface information in order to identify a potential geometry and location of weakness zone which contains an old slip surface from previous landslides. According to [4], an unuseful survey can occur due to lack of collaboration among the site geologists, engineers and geophysicists since the geological problem solution is strongly dependent on the appropriate synthesis of all available information.

Hence, this study adopts the seismic refraction tomography technique as one of the geophysical methods to investigate the landslide affected areas. This method can imaged the subsurface information in a two dimensional (2D) perspective giving more appropriate information and interpretation. The basis of seismic refraction investigation is in the measuring of the time taken for a seismic wave to travel from one location to another location. This time taken is a necessarily a function of elastic modulus of the material through which the wave travels. The underground wave motion is based on Snell's law principle and is used to study the layering below the earth surface. Waves travelling in a medium (soils/rocks) will be subject to the elastics characteristics and can move in all directions through the means of direct, reflected and refracted wave. The motion of a wave at a certain distance will be recorded as a time function. From the wave arrival times, the layers and structures in the subsurface can be determined. However, the effectiveness of geophysical methods largely depend upon the presence of a significant and detectable contrast in the physical properties of different lithological units as the seismic P-wave velocity are normally affected by density, lithology, porosity, lithification, pressure, fluid saturation and anisotropy of the geomaterials. According to [2], lithology, porosity and interstitial fluids of geomaterials can influenced the success of interpretation of subsurface profile based on the seismic P-wave velocity contrast. Furthermore, the reliability performance of any individual geophysical methods will always depends on fundamental physical constraints, e.g. penetration, resolution, and signal to-noise ratio [10] and [4]

According to [10], [11], [4] and [13], geophysical method such as the seismic methods can be practically adopted to determine the internal distribution of materials within a slope, identifying sliding surface geometry, water effect on slope, landslide material physical properties and mass movement. In its application to ground damage through landslides, seismic refraction method will detect the reduction of stiffness or rigidity of the sliding mass relative to the underlying undisturbed sediments or bedrock [14]. The velocity drop or decrease will give some indication regarding the presence of a weakness zone. Based on [15], the decrease of velocity may be a function of the factors such as the processes that sediments undergo like expansion upon shearing which can increase the water content and porosity, the presence of shear planes in the upper mobile zone caused by a groundwater barriers and alteration by leaching and groundwater through weathering. As reported in [13], geophysical methods have also been used to identify landslide slip surfaces. Seismic survey can be an attractive alternative to borings when access is difficult and/or the landslide covers an extensive area [16]. Seismic refraction is the technique mainly used to investigate near surface geological structures. This method has been employed not only to find out the depth of bedrock and the seismic velocity of layers but also to investigate gravitational slope deformation [17]. The application of electrical resistivity and seismic methods can help in the identification of clay layer and the fault zone associated with the landslide failure to be successfully being mapped [18]. The application of seismic refraction can also be successfully being used in the determination of landslide properties such as depth and dip of a slip surface/shear plane [19], [11] and [20].

There are several advantages in the geophysical method with particular references to seismic refraction method were due to its efficiency in term of cost, time and environment. Furthermore, seismic refraction is essentially a surface technique with staged data acquisition stages that can preserve the site condition

and environment. According to [21], although the method requires a ground contact, it caused minimal and damage to the site and is normally considered negligible. Geophysical tests in soil/rock exploration are usually low in cost [22] and [12]. Field time is usually short and ranges from one to three days for most projects [16]. As stated by [23], geophysical methods can be implemented more quickly and less expensively and can cover greater areas more thoroughly. Geophysical methods are generally less expensive, less invasive and less time consuming; they provide a large-scale characterisation of the physical properties under undisturbed conditions [9].

Finally, the objectives of this paper are to

- (1) present and understand a problematic subsurface profile due to landslides and geomaterials features for rehabilitation and mitigation purposes and
- (2) to verify the features based on previous/concurrent borehole exploration data.

2. Methodology

Overall methodology of this study was given in the flowchart as Figure1.

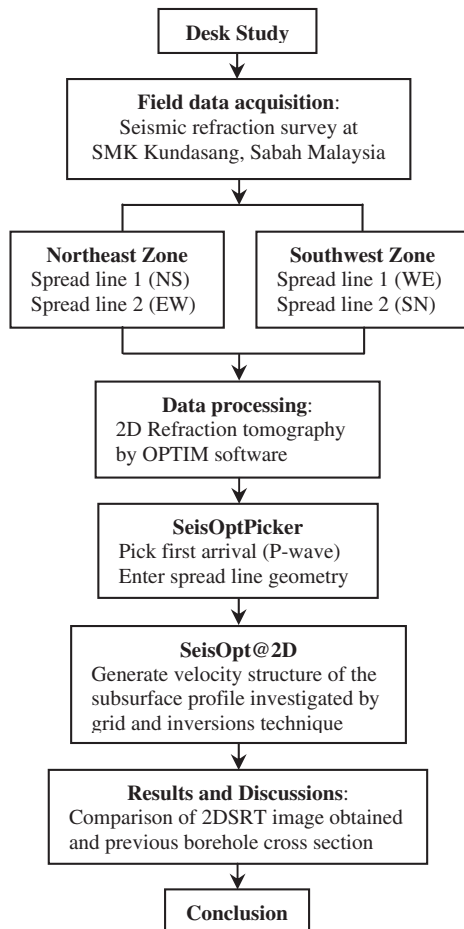


Fig. 1. Analysis path to infer seismic refraction investigation on near surface landslides at Kundasang area in Sabah Malaysia

2.1. Study area and geologic setting

This study is located along the bank of Kundasang Valley on the southeast side of Mount Kinabalu. Generally, the site study has mix topography of undulating hilly terrain and surrounded by a developing town and village near the foothill of Mount Kinabalu. This study was conducted at Kundasang, Sabah area specifically at SMK Kundasang, Sabah.

Generally, the geology of Kundasang comprises of a Tertiary Sedimentary rock known as Crocker and Trusmadi Formation and the boundary of both formations was separated by a fault [24] and [25]. Trusmadi rock formation obtained here is a thick sheared black argillaceous which consist of a lens of grey sandstone in different sizes. According to [7], SMK Kundasang was located on two layers of geomaterials. The first layer consist is thin to medium grained sandstone interbedded with light mudstone while the second layer consist of black argillaceous rock (mainly shale) with a little sandstone and mudstone.

2.2. Equipment

The seismic refraction equipment consists of three main components which is source, detector and record. The seismic source was generated by a 12 pound of sledge hammer (hammering on a striker plate). A 24 channel of 28 Hertz vertical geophone was used as detector while ABEM Terraloc MK-6 Seismograph was used to record the seismic signal. The raw data measured on site was analyzed and interpreted by Optim software.

2.3. Data acquisition and processing

The spread line (SL) was selected based on the research objective and interest (normally nearest possible to the existing borehole within a critical ground damage zone observed). Then, a total of twenty-four (24) geophones are fixed on the ground surface and connected with a two seismic land cables with total of twenty-four (24) take out. These seismic cables are used for sending the velocity signal from each geophone to the seismograph to record the seismic signals. After setting up the instrument, the operator adjusts the digital seismograph and confirms the stand-by of the shooter. The operator monitors the noise condition on seismograph (for example, noise caused by moving vehicles, vibrating machinery etc) and instruct the shooter for hammering (creating a source) during the lowest possible/acceptable noise. The seismic wave travels down and along the different refractor boundaries. Only critically refracted waves are concerned in this survey. The refracted energies are detected by the geophones. After that, it is converted to digital signals before storing in the stacking memory. The seismograph amplifies the electrical signal from several thousand to several ten thousand times and recorded the results in the floppy disk as the waveform data. When the trace is analysed, a record is stored in floppy disk for further processing. This study applied a two offset shots, two end shots, and three center shots for efficient processing. The seismic spread lines used 5 m of geophone spacing interval for SL 1, 2 and 3 while 4 m of geophone spacing interval was used for SL 4. Data processing can be done by transferring the raw data from ABEM Terraloc MK-6 to the computer. The data analysis was carried out by utility software that available for generating the model of the subsurface profile. The software used in this study is OPTIM which consist of SeisOptPicker and SeisOpt@2D processing. SeisOptPicker was used to pick the first

arrival (P-wave) while the SeisOpt@2D software used to calculate velocity and depth thus generating the velocity distribution representing the model of the subsurface profile studied.

3. Results and Discussions

Four spread lines representing SL1 and SL2 (Northeast Zone) and SL3 and SL4 (Southwest Zone) with total length of 437 m were conducted during the data acquisition stages and the results was given in Figure 2 to 5. It was found that there are three main layer of velocity representing three types of geomaterials with possible different characteristics. Primary velocity (v_p) value which related to this study area as reported by previous researcher was given in Table 1 while a summary of seismic lines configuration and findings were given in Table 2 and 3.

Table 1. Typical primary velocity (v_p) of some of the earth materials

Description	Primary velocity, v_p (m/s)
Air [26]	331.5
Soil [27]	250 – 600
Sandstone [27]	1500 – 3000
Shale [27]	1200 – 3000
Hard rock [27]	Above 2400
Rock, weathered, fractured, or partly decomposed [28] and [22]	610 – 3048
Water [26]	1400 -1600

3.1. Northeast (NE) Zone

Two spread lines were conducted in this area representing spread line 1 (North South: NS) and spread line 2 (West East: WE) as given in Figure 2 and 3.

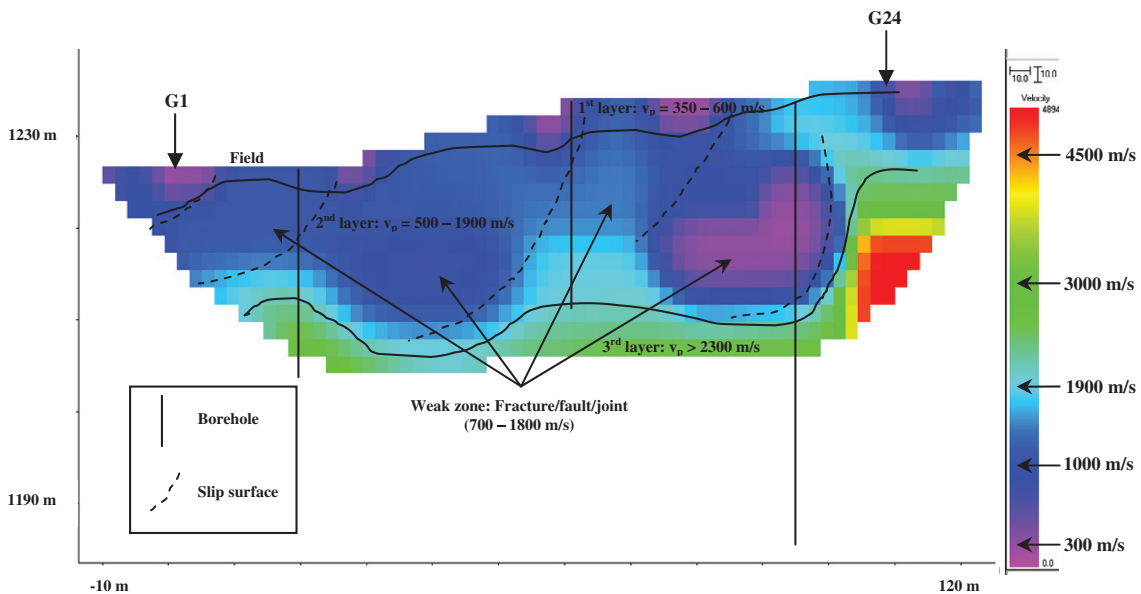


Fig. 2. Spread line 2 in North south (NS) alignment

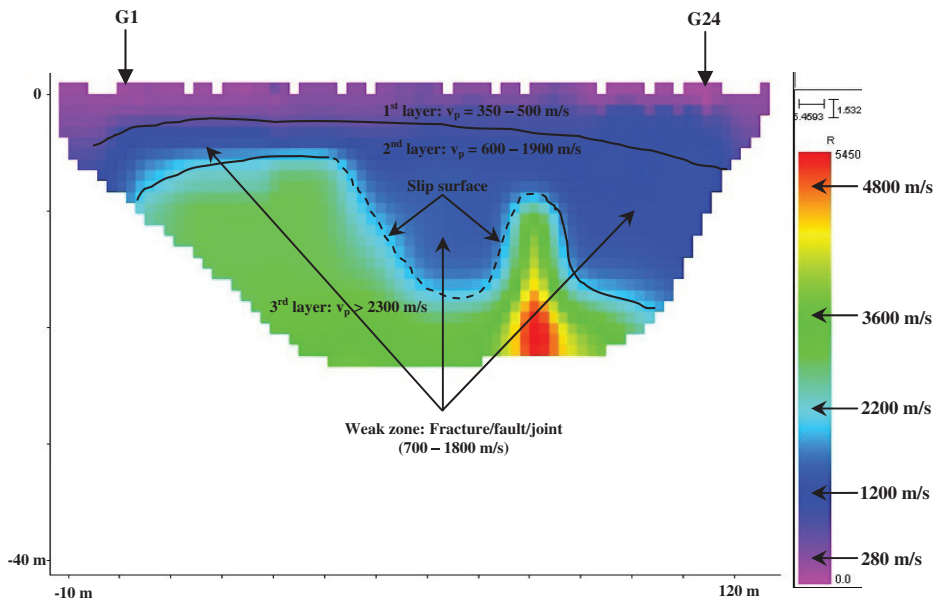


Fig. 3. Spread line 2 in East west (EW) alignment

3.2. Southwest (SW) Zone

Two spread lines were conducted in this area representing spread line 3 (West East: WE) and spread line 4 (South North: SN) as given in Figure 4 and 5.

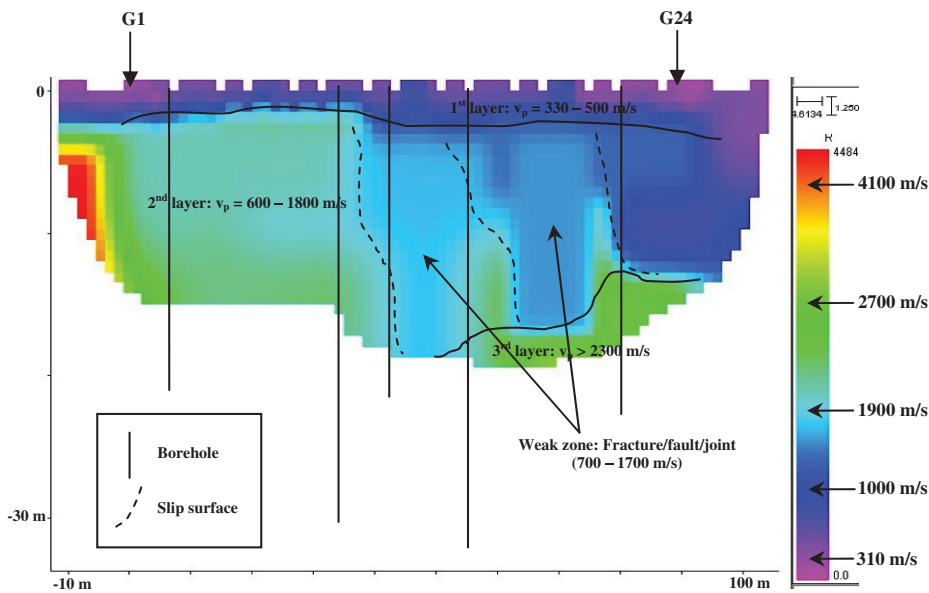


Fig. 4. Spread line 3 in West east (WE) alignment

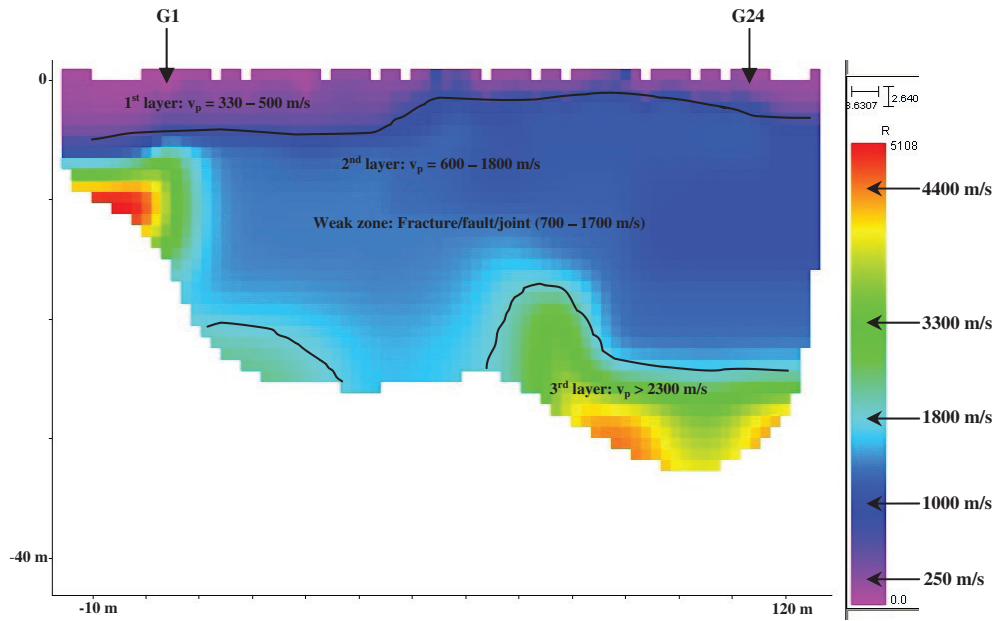


Fig. 5. Spread line 4 in South north (SN) alignment

Table 2. Configuration and findings from seismic refraction survey at SMK Kundasang, Sabah

No	Zone	Seismic Line Alignment	Spread Line Geometry	Maximum depth of penetration, d (m)	Velocity structure, v_p (m/s)	Thickness layer, t (m)	Damage zone/ Weak zone features, v_p & t (m/s) & (m)	Damage zone/ Weak zone obtained, v_p , t, w & l (m/s) & (m)
1	Northeast (NE)	Spread Line 1 (NS)	Geophone Spacing: 5 m 1 st offset: 10 m 2 nd offset: 6 m 7 shot point location	25	1 st : 350 - 600	1 st : 0 - 2	v_p : 700 - 1800 t: 3 - 20	v_p : 700 - 1800 t: 3 - 20
					2 nd : 500 - 1900	2 nd : 2 - 23		
					3 rd : > 2300	3 rd : 8 - 23		
2	Spread Line 2 (EW)	Geophone Spacing: 5 m 1 st offset: 10 m 2 nd offset: 10 m 7 shot point location	24	1 st : 350 - 500	1 st : 0 - 4	v_p : 700 - 1800 t: 5 - 20	v_p : 700 - 1800 t: 3 - 20 w: 75 l: 100	
				2 nd : 600 - 1800	2 nd : 2 - 17			
				3 rd : > 2300	3 rd : 6 - 24			
3	Southwest (SW)	Spread Line 3 (WE)	Geophone Spacing: 4 m 1 st offset: 10 m 2 nd offset: 10 m 7 shot point location	19	1 st : 330 - 500	1 st : 0 - 4	v_p : 700 - 1700 t: 4 - 19	v_p : 700 - 1700 t: 4 - 25 w: 57 l: 115
					2 nd : 600 - 1800	2 nd : 4 - 19		
					3 rd : > 2300	3 rd : 13 - 19		
4	Spread Line 4 (SN)	Geophone Spacing: 5 m 1 st offset: 14 m 2 nd offset: 10 m 7 shot point location	33	1 st : 350 - 600	1 st : 0 - 6	v_p : 700 - 1700 t: 5 - 25	v_p : 700 - 1700 t: 5 - 25	
				2 nd : 700 - 1800	2 nd : 2 - 25			
				3 rd : > 2300	3 rd : > 25			

Table 3. Subsurface geomaterials results from 2D seismic refraction survey at SMK Kudasang, Sabah

Zone	Spread Line	Layer 1 (L1)	Layer 2 (L2)	Layer 3 (L3)	Primary velocity, vp (m/s)	Thickness (m)
Northeast (NE)	1 (NS)	Residual soil: Unconsolidated material of soil with some pore/voids within the layer, original rock structure destroyed	(i) Highly to completely weathered zone: Rock material was in degraded condition, original structure of rock mass may destroy and discernible, contain relict characteristics, e.g: Poor rock mass quality with a mixture of corestone and soil (ii) Moderately weathered zone: Small percentage of degraded rock, e.g: rock with a fractures with small percentage of soil	Slightly weathered to fresh bedrock	L1: 350 - 600 L2: 500 – 900 & 900 - 1900 L3: > 2300	L1: 0 - 2 L2: 2 - 23 L3: 8 - 20
	2 (EW)	Residual soil: Unconsolidated material of soil with some pore/voids within the layer, original rock structure destroyed	(i) Highly to completely weathered zone: Rock material was in degraded condition, original structure of rock mass may destroy and discernible, contain relict characteristics, e.g: Poor rock mass quality with a mixture of corestone and soil (ii) Moderately weathered zone: Small percentage of degraded rock, e.g: rock with a fractures with small percentage of soil	Slightly weathered to fresh bedrock	L1: 350 - 500 L2: 600 – 900 & 700 - 1900 L3: > 2300	L1: 0 - 4 L2: 2 - 20 L3: 6 - 24
Southwest (SW)	1 (WE)	Residual soil: Unconsolidated material of soil with some pore/voids within the layer, original rock structure destroyed	(i) Completely weathered zone: Degraded condition of rock material with discernible original rock structure, contain relict characteristics, e.g: mixture of corestone and soil (ii) Moderately weathered zone: Small percentage of degraded rock, e.g: rock with a fractures with small percentage of soil	Slightly weathered to fresh bedrock	L1: 330 - 500 L2: 600 – 900 & 900 - 1800 L3: > 2300	L1: 0 - 3 L2: 4 - 19 L3: 13 - 19
	2 (SN)	Residual soil: Unconsolidated material of soil with some pore/voids within the layer, original rock structure destroyed	(i) Completely weathered zone: Degraded condition of rock material with discernible original rock structure, contain relict characteristics, e.g: mixture of corestone and soil (ii) Moderately to highly weathered zone: A mixture of small and large quantity of degraded rock mass condition, rock mass affected by fractured with small relict characteristics, poor and moderate rock mass quality, e.g: Rock with weathered discontinuities and corestone	Slightly weathered to fresh bedrock	L1: 350 - 600 L2: 700 – 900 & 700 - 1700 L3: > 2300	L1: 0 - 6 L2: 2 - 25 L3: > 25



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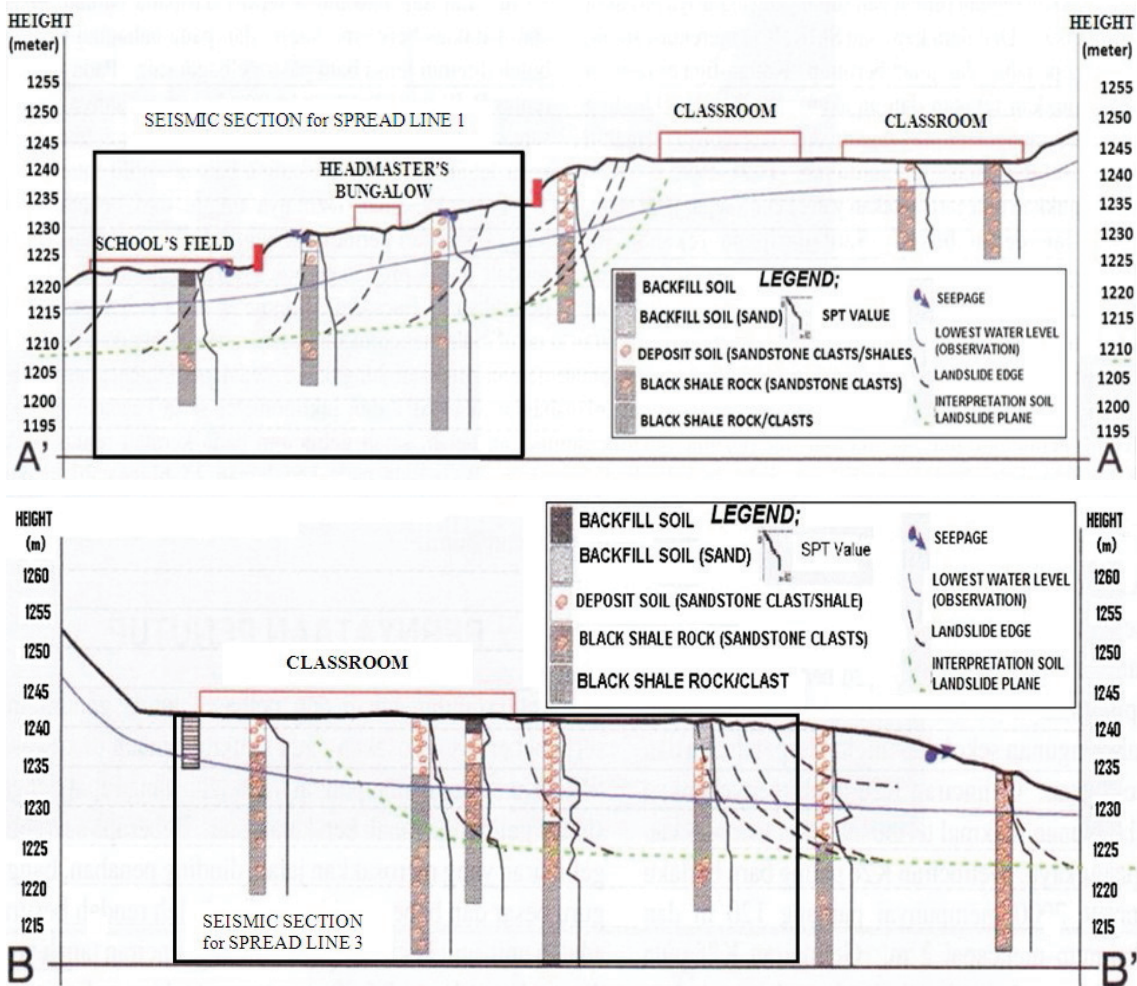
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Fig. 6. Subsurface cross section of landslides based on borehole results at SMK Kundasang [7]

The seismic refraction results conducted were compared and correlated with a previous researcher [7]. Comparison was made based on borehole cross section A – A' and B – B' as given in Figure 6 and primary velocities from Table 1. According to [19], [20] and [29], the using concept of seismic refraction in locating weakness plane (slip surface /shear plane) is that the materials above the weakness plane consist of great difference properties such as a slipped mass will exhibit lower seismic velocity than those

underlying in situ strata. The seismic refraction is capable to represent a landslide mass by low P-wave velocity while the high P-wave velocity represents the landslide bedrock [11]. As reported by [7], slip surface zone was located at depth of 15 – 20 m from the ground surface based on borehole exploration consists of standard penetration test (SPT), inclinometer and geology condition at the area. Based on 2DSRT conducted in this study, the weak zone with a potential slip surface observed from both zones in this study was located at 2 – 25 m depth with 57 and 75 m width and 100 m and more as its length. As referred to Table 2 and 3, the subsurface profile investigated consists of three major layers of loose/unconsolidated materials, weathered materials and hard materials/bedrock. The landslide was detected between layer 1 and 3 where the materials show some great different of properties based on primary velocity obtained. Furthermore, 2DSRM also reveals that the landslide was interconnected form both zone investigated starts from southwest zone towards the northeast zone.

The variation of weak zone and depth obtained from this study then previous may occur because of the present subsurface materials has suffered by an additional weathering process thus producing another poor rock mass quality. According to [30], rates of weathering were influenced by rock characteristics (types of rock, mineral composition and rock physical condition) and climate (related to temperature and moisture). In tropical climate country as Malaysia, weathering process is much progressive due to the abundance of rainfall and moisture thus accelerating the transformation of homogeneous subsurface material into heterogeneous subsurface materials [31]. Generally, humid tropical zone as Malaysia experienced high rainfall, often seasonal with high temperatures in a longer period [32]. This study was conducted seven years after the past researchers complete their studies. According to [33], major new fractures may form or be extended, incipient fractures may lose tensile strength and the discontinuities rock wall may weaken, leading to reduce shear strength and stiffness. Water can easily infiltrate underground thru surface crack/failure of structure or ground tension crack exist hence will intensively attack and weaken the subsurface geomaterials especially by chemical weathering process. Chemical weathering below surface takes place via water movement through mass and materials that may passes thru joint, fractures and other discontinuities and the distribution of mass weathering may reflect both minor and major joint set spacing and orientation and the presence of faults [34]. The weathered fractured materials can be disintegrate and decomposed into a fine grained materials such as mineral, sand, clay, silt, etc. that can filled an existing joint and fractured. Hence, this condition are also may contribute to a different subsurface primary velocity obtained. For example, a compacted infilling materials can increased the velocity structure value compared to the porous and loose materials.

The local factors that cause ground damage with particular reference of landslides in SMK Kundasang was identified based on this area that lies on a regional landslides system of Kundasang's Landslides Complex as reported by [7]. Furthermore, earthwork history involving cut and fill materials on the original ridge topography area may also contribute to weaken the ground foundation in a long term condition since water flow, soil and rock condition was already disturbed and altered. According to [16], cut slopes made through sedimentary rock may pass through hard rock, partly fully cemented sand, clay and shale etc. and differential weathering may erode the less resistance rock layers undermining the slope above over a period of years to allowed seepage process that can accelerate the weathering and erosion between two layers of different permeability in landslides are the result of differential weathering. The current topography of SMK Kundasang area was a low gradient undulating area starting from the high part at Southwest zone to the lower part at Northeast zone. Hence, the water will flow and weaken the subsurface geomaterial according to this current topography direction. The situation can be worse during a heavy rainfall with the surface runoff permeating underground thus increasing the groundwater level in saturated condition and increase the soil mass. Based on [22], the intense rainfall will raise groundwater level rapidly condition to the ground surface and this would result in a sudden increase in pore pressure which would reduce the shearing resistance of geomaterial and finally lead to a failure.

The effect of geological structure is also regarded as one of the several factors that contribute the damageability condition in Kundasang area especially during an earthquake. According to [5], the entire district of Kundasang has been exposed to minor earthquake tremor and continuous translatory soil movement that contributing to frequent landslides in the area. This seismic activity has affected structural geology in several areas in Sabah including Kundasang. Kundasang was located at the intersection of regional fault zone of Quaternary age as reported by [6]. Locally Kundasang is located near to the Lobou-lobou fault line which is considered as a part of the Crocker fault zone in northern segment that intersect with another regional Mensaban fault zone. According to [6], Lobou-lobou fault segment is a currently active fault with a sinistral displacement. Mass movements in SMK Kundasang can easily be observed through ground damage by an existing fault, tension crack and fractured or failure of manmade structure. The Trusmadi rock is one of the unstable geomaterial present identified as one of the root causes of widespread and continuous mass movement in Kundasang area by a still rising Kinabalu pluton [35]. Borneo Post (2011) also reported that a study conducted by the South East Asia Disaster Programme Research Institute (SEADPRI) and the Department of Mineral and Geoscience Malaysia already confirmed that Kundasang has a sensitive, fragile and complex geological system.

4. Conclusions

The problematic subsurface profile in landslides was successfully being investigated using 2D seismic refraction tomography. The geometry and primary velocity distribution of SMK Kundasang has determined by analyzing seismic refraction data obtained along the NE and SW zones and the result has shown a good similarity with the borehole data. This finding has proved that this method is able to predict the landslides features in order to assist the conventional borehole data. 2DSRT was successfully mapped the subsurface profile which able to extend the surface information mapped by geodynamic mapping and other physical mapping. The mechanics and physical characteristics of the landslide can be easily recognized. The determination of shape and depth of the subsurface landslide which caused ground damage are easier and cheaper than with conventional borehole method. The information from the refraction survey was useful for rehabilitation and mitigation purposes such as rippability and excavation works. This geophysical method is suitable for our sustainable ground investigation since it can reduce time, money and compliment others conventional method especially by its 2D surface technique of investigation. The application of seismic refraction tomography in conjunction with geological and borehole information was effectively being applied for mapping of ground damage with particular reference of near surface landslides.

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Appendix



Fig. 7. Location of spread line (SL) in SMK Kudasang Sabah, Malaysia

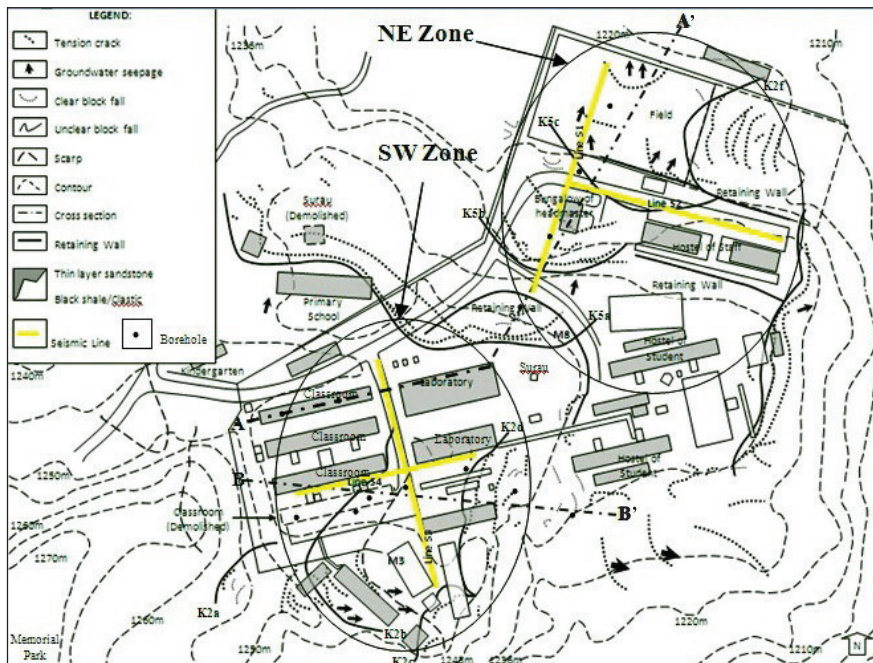


Fig. 8. Location of spread line conducted with some of the geodynamic mapping in SMK Kudasang Sabah, Malaysia [7]