Earth Science Partnership
Consulting Engineers | Geologists | Environmental Scientists

Godre'r Graig Village
Preliminary Landslide Hazard and Risk Assessment

Report Reference: ESP.7372e.3337

Earth Science Partnership
Consulting Engineers | Geologists | Environmental Scientists

33 Cardiff Road, Taff's Well, CARDIFF, CF15 7RB ☎ 029 2081 3385
✉ enquiries@earthsciencepartnership.com www.earthsciencepartnership.com

Godre'r Graig Village
Preliminary Landslide Hazard and Risk Assessment

Prepared for:
Neath Port Talbot County Borough Council
The Quays, Baglan Energy Park,
Brunel Way, Briton Ferry,
SA11 2GG

Report Reference: **ESP.7372e.3331**

Revision	Status	Date	Written by	Checked and Approved by
0	Draft	March 2020	Mat Elcock BEng (Hons) FGS	Matthew Eynon BSc (Hons) MSc CGeol EurGeol FGS RoGEP Specialist
1	Draft	March 2020		
2	Final	June 2020		
		Signature:		M Eynon
Notes:	1. Once issued this document is Uncontrolled, for the latest version and/or to confirm you have authorisation to use it please contact the Earth Science Partnership at enquiries@earthsciencepartnership.com or by telephone at 029 2081 3385. 2. This document has been optimised for double sided printing and therefore may produce some blank pages when printed single sided.			

Contents

1 Introduction

1.1 Background

Neath Port Talbot County Borough Council (hereafter known as the Client) have instructed Earth Science Partnership Ltd (ESP) to undertake a Preliminary Landslide Hazard and Risk Assessment for the village of Godre'r Graig, located in the Tawe Valley.

The general location of the study area is shown on Figure 1.

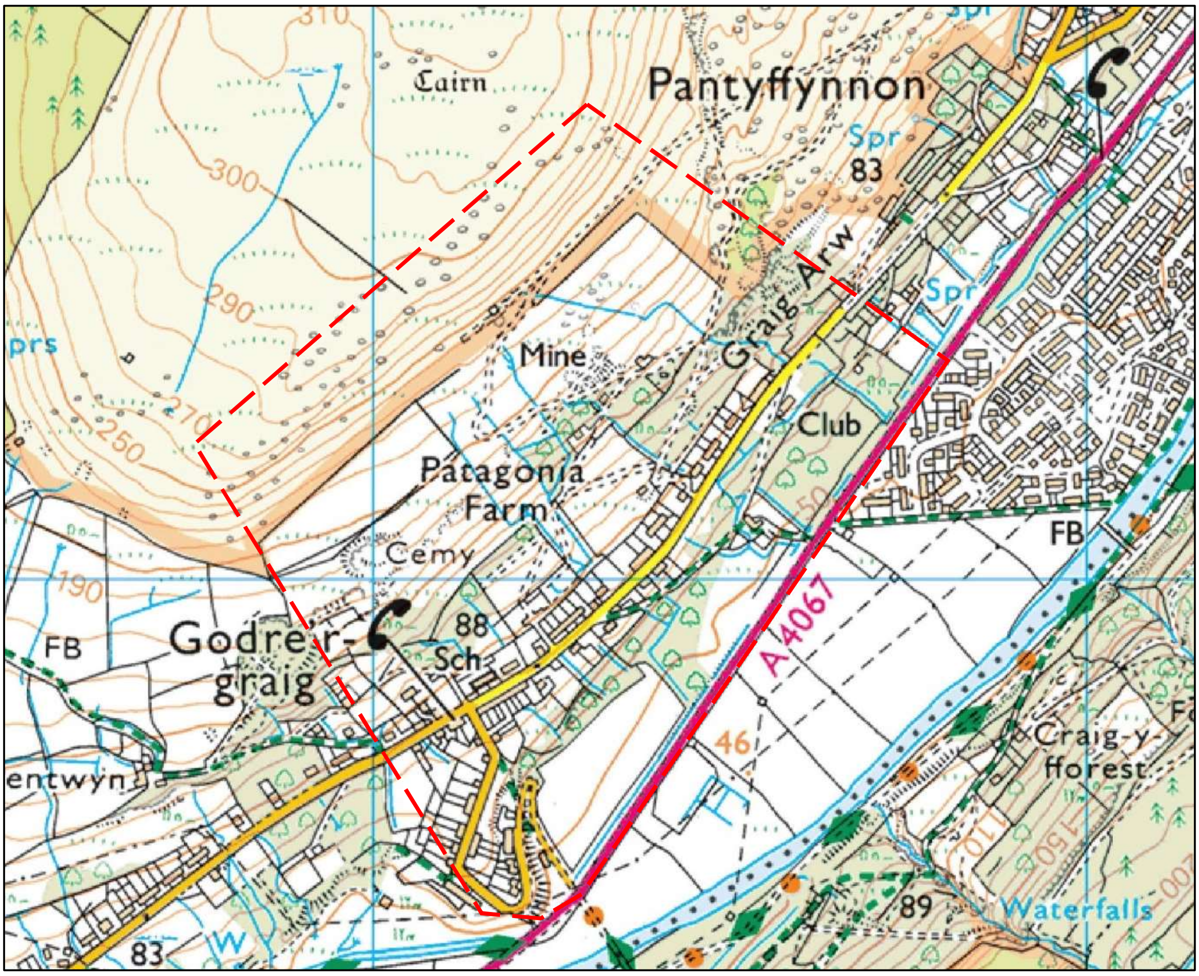

Figure 1: General Study Area 1:10,000 (Ordnance Survey License No.: AL100015788).

The study area for the assessment was chosen as the slopes above Godre'r Graig to the summit of Mynydd Allt-y-grug and nearby terrain for similar features in a similar geological and geomorphological setting.

Earth Science Partnership have undertaken a Landslide Hazard and Risk Assessment for Godre'r Graig School in July 2019 (ref. 7234e.3221). A more detailed assessment of a man made landslide hazard identified in the first report was considered further in a second assessment by ESP (ref. 7234e.3302). Pertinent information from both these assessments are included in this wider assessment as necessary.

This assessment does not consider the risks to the school, only residential properties in Godre'r Graig. If risks to the school would like to be understood, these can be read in ESP reports, refs.

7234e.3221 and 7234e.02.3302. Consideration for members of the public using the cemetery has however been provided in the later stages of the risk assessment.

1.2 Objective and Scope of Works

As discussed in Section 1.1, the aim of this report is to provide an assessment of the terrain above Godre'r Graig (study area defined in Section 1.1) and assess any hazards and outline the risks they pose to residents in Godre'r Graig.

The scope of works for the investigation was mutually developed with the Client and ESP within an agreed budget, and comprised:

- A geological and historical desk study;
- Obtaining aerial photograph and subsequent interpretation, including stereographical analysis;
- A site visit for orientation and initial morphological assessment;
- Generation of a preliminary morphological map with the assistance of low-level LiDAR information;
- Generation of a conceptual engineering geological model; and
- Development of a preliminary qualitative assessment of the hazards/risks and definition of next steps.

Some elements of this assessment, such as the data presentation, hazard identification and qualitative risk assessment are taken from the guidelines set out within a journal from the Australian Geomechanics Society (AGS, 2007) and subsequent papers to standardise its use worldwide (Fell et al 2008)1. There are no British Standards or Eurocodes for the assessment of landslide hazard and risk. It should be noted that this assessment is not in full accordance with the AGS guidance due to the availability of landslide data in local area.

The terms of reference for the assessment are as laid down in the Earth Science Partnership proposal of 14th October 2019 (via email). The assessment was undertaken between October 2019 and June 2020.

1.3 Report Format

This report includes a geological and historical desk study, an aerial photograph interpretation including the findings of two site reconnaissance visits to undertake a preliminary morphological assessment of the site. The information gained is used to undertake a Hazard Identification Assessment following general principals of the AGS (2007) guidance and a qualitative assessment with recommendations provided. This report is issued in a digital format only.

---

[1] Fell et al (2008) reporting on behalf of JTC-1 (Joint Technical Committee on Landslides and Engineered Slopes, an International Association of Engineering Geology and the Environment (IAEG), International Society for Rock Mechanics and Rock Engineering (ISRM) and International Society for Soil Mechanics & Geotechnical Engineering (ISSMGE) collaboration exercise, i.e. all relevant international professional geotechnical societies) provides guidelines for landslide hazard and risk assessments. JTC-1 is largely based on AGS (2007) with minor modification for international implementation. The Engineering Group of the Geological Society is the UK National Group of the International Association of Engineering Geology (IAEG).

1.4 Limitations of Report

This report represents the findings of the brief as detailed in Section 1.1. It should be appreciated that only a limited intrusive investigation has been undertaken to date. Should an alternative current land use or structure be considered, the findings of the assessment should be re-examined relating to the new proposals or land uses. Where preventative, ameliorative or remediation works are required, professional judgement will be used to make recommendations that satisfy the site-specific requirements in accordance with good practice guidance.

Consultation with regulatory authorities will be required with respect to proposed works as there may be overriding regional or policy requirements which demand additional work to be undertaken. It should be noted that both regulations and their interpretation by statutory authorities are continually changing.

This report represents the findings and opinions of experienced geo-environmental and geotechnical specialists. Earth Science Partnership does not provide legal advice and the advice of lawyers may also be required.

2 Desk Study

The information presented in this section was obtained from desk-based research of sources as detailed in the text. The study area was visited in the June 2019 and January 2020 during changeable weather conditions.

2.1 General Description of Study Area

The study area is located in the Tawe Valley, on the eastern flank of Mynydd Allt-y-grug, between Pontardawe and Ystalyfera.

Godre'r Graig village is typically formed by housing that lines both Gnoll Road and Graig Road. Graig road is situated part way up the valley side and runs parallel to the valley contours, Gnoll road, via a series of hairpin bends connects Graig Road with the main road at the base of the Valley, he A4067. A school is located near the centre of Godre'r Graig, near the junction of Gnoll Road and Graig Road.

Land usages in Godre'r Graig typically comprise residential properties, however, there are some areas of animal grazing and areas covered by trees. A cemetery, with an associated small car park is located some 50m north of the school. The cemetery has a stone wall boundary and a concrete track providing access to the higher portions of the cemetery.

Land to the west of Graig Road, behind the houses for a general distance of 30m is used for animal grazing, as it is separated into several fields by post and wire fences. The land beyond the rough grazing ground is typically covered in trees and bracken and although not officially Common Land, it appears unused and overgrown. Further grazing is noted near to the base of a scree, or talus slope on the upper parts of Mynydd Allt-y-grug, and this is separated by a dry stone wall.

There are two distinct quarries upslope of the school and numerous concave features which are also likely to be associated with previous mining activities.

From the River Tawe at the bottom of the valley, initially the slopes are relatively gentle and become steeper as you pass Graig Road going uphill.

The approximate National Grid Reference for the school near the centre of Godre'r Graig is (SN) 275155 206870 and the postcode is SA9 2NY.

2.1.1 General Topographic Setting

The topography of the area slopes downward toward the southeast from the relatively steeply sloping, eastern flank of Mynydd Allt-y-grug to the west. The Tawe Valley forms a typical U-shape valley, however, there appear to a gently stepped nature to the valley side and this is likely to represent the harder and softer layers of bedrock (sandstone and mudstone) weathering at different rates.

The topography has been altered by man with two large quarries noticeable in the study area, and numerous other mining features which has generated steeper slopes and spoil mounds.

2.1.2 Shallow Slips

There is an area in the centre of the study area that was the subject of the ESP 2019 assessment and were visually inspected on the 6th June, which were noted to be relatively shallow depressions with springs and hydrophilic vegetation helping to delimitate their extent and width. A cutting for a track, circa 0.5m high, crosses the toe of two features and the exposure showed the slipped mass to be Colluvium, no evidence of movement could be seen in the cut slope.

2.2 History

The site history has been assessed from a review of available historical Ordnance Survey County Series and National Grid maps. The historical maps are presented in Appendix A and the salient features since the First Edition of the County Series maps are summarised below.

The first historical map studied, dated 1877, shows Graig road in its current day position with houses either side. Gnoll road has not been constructed by this time. A school is shown on the southeastern side of Graig road and the surrounding area looks to be agricultural with trees/forests indicated.

The cemetery is shown in its present day location, two quarries are located around 200m west, or upslope of Graig Road and a further quarry is located in the north of the study area. The westernmost quarry was labelled as Cwar Pentwyn and the historical maps show it as disused on the 1964 map, so became disused between 1948 and 1964.

A series of spring are labelled in the northwestern portion of the study area.

There are numerous coal levels shown in the northern portion of the study area, which through time include localised spoil tips. By 1897, further coal levels to the west were common and the maps suggest that the levels are disused by the 1960s.

The school south of Graig road changes to a Indt. Chap. which is likely to be an independent chapel on the 1918 map and the existing Godre’r Graig school was constructed between maps dated 1899 and 1913.

Houses along Gnoll road were also constructed between 1899 and 1913, there was significant development in the south of Godre’r Graig, with sewerage works, tramways and embankments abutting onto the former location of the Swansea Canal.

Swansea Canal was infilled or bridged in the early 1970 when Gnoll road was connected to the new main road in the base of the valley floor.

The 1960, 1:2,500 historical map provides good detail on the mining entries in the Godre’r Graig area and there are some 20 mine adits approximately 200m west of Graig road in the hillside of Mynydd Allt-y-grug, with a large number around Patagonia Farm.

2.3 Hydrology

A review of the historical maps have showed a series of springs that emanate in the hillside above the Graig road. They all flow downhill, toward the east or southeast.

Consideration to the position of the springs and the underlying geology, it is considered likely that they emerge at locations where more permeable strata, such as a sandstone, overlies less permeable strata, such as mudstone or siltstone units.

Water has also been noted to be flowing out of old mine adits, which are likely to be draining old workings.

2.4 Geology

The published 1:10,560 scale geological maps for the area (Inserts 2a, Sheet SN 70 NE and Insert 2b, Sheet SN 70 NW) indicates that the hillside is predominantly made up of the Upper Coal Measures (now formally known as the South Wales Upper Coal Measures Formation) which underlie a sandstone outcrop at the top of Mynydd Allt-y-grug of the Rhondda Member, which is part of the Pennant Sandstone Formation.

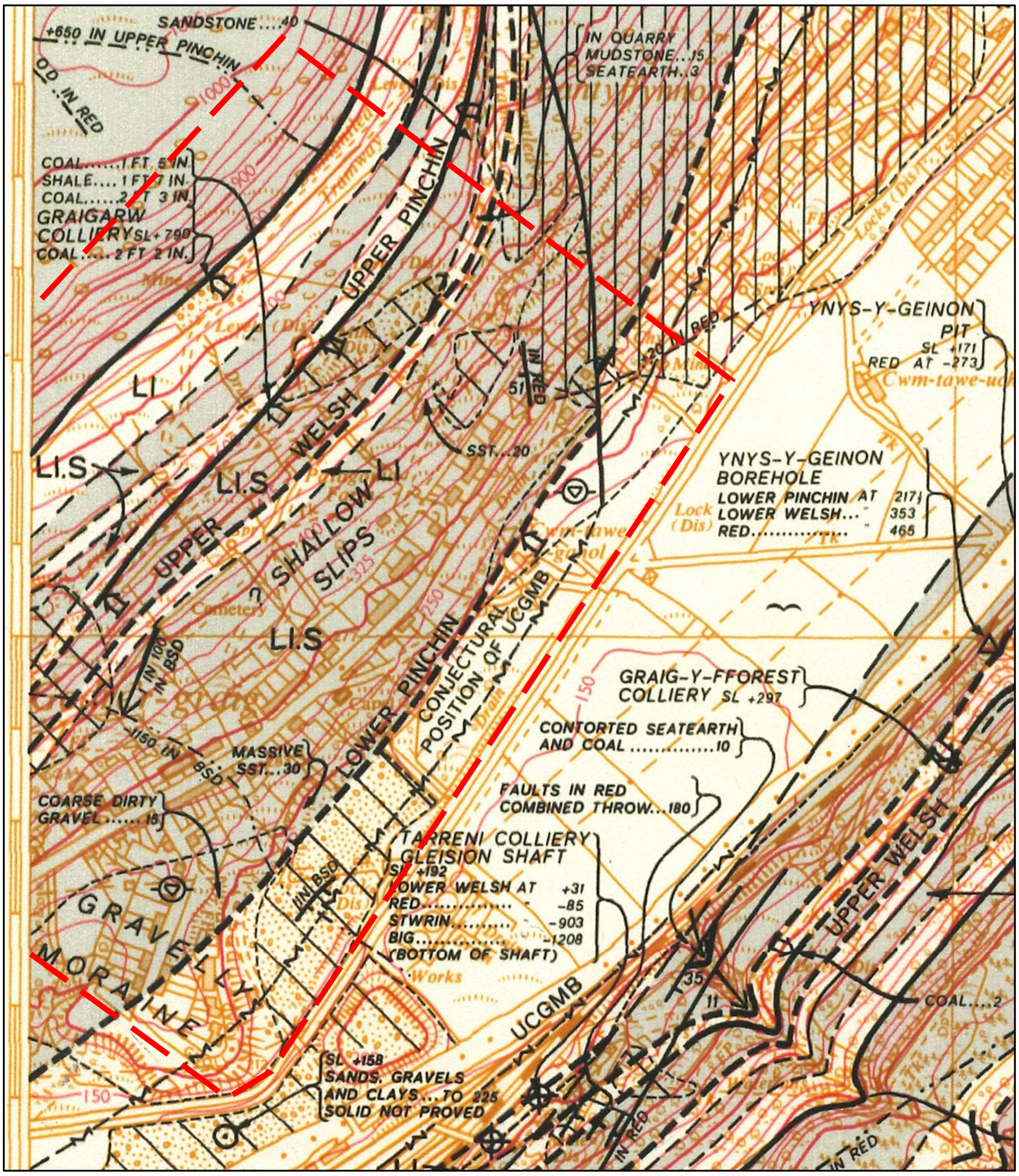

Figure 2a: Geological Map SN70NE extract. Red line shows study area. (BGS licence number: C15/05 CSL) Not to scale

The No. 2 Rhondda coal seam outcrops at the base of the Pennant Sandstone Formation and forms the boundary between the (older) Upper Coal Measures and the overlying (younger) Rhondda Beds which comprise sandstone.

The Upper Coal Measures comprises a series of units formally known as the Llynfi Beds, these are now referred to as the Llynfi Member and according to the Geological Memoir for the area, the

Llynfi Member is essentially argillaceous, and contains sandstones bands within it that are generally thin and in-persistent.

The strata above the No. 2 Rhondda or roof rock in the overlying Rhondda Member is understood to be a Conglomerate.

The published 1:50,000 scale geological map for the study area (Sheet 230, available on the website of the British Geological Survey, 2019) generally confirms that above stratigraphy and shows the beds to be dipping toward the south at angles of between 3° and 5°.

As mentioned above the No. 2 Rhondda coal seam is situated high above the village, however there are other coal seams that outcrop in the hill side, which include the Upper Pinchin and the Upper Welsh. Another seam, the Lower Pinchin coal seam is likely to outcrop at the base of the valley. All these seams are widely worked in the area, noticeably the Upper Pinchin which is located in the hillside above the village.

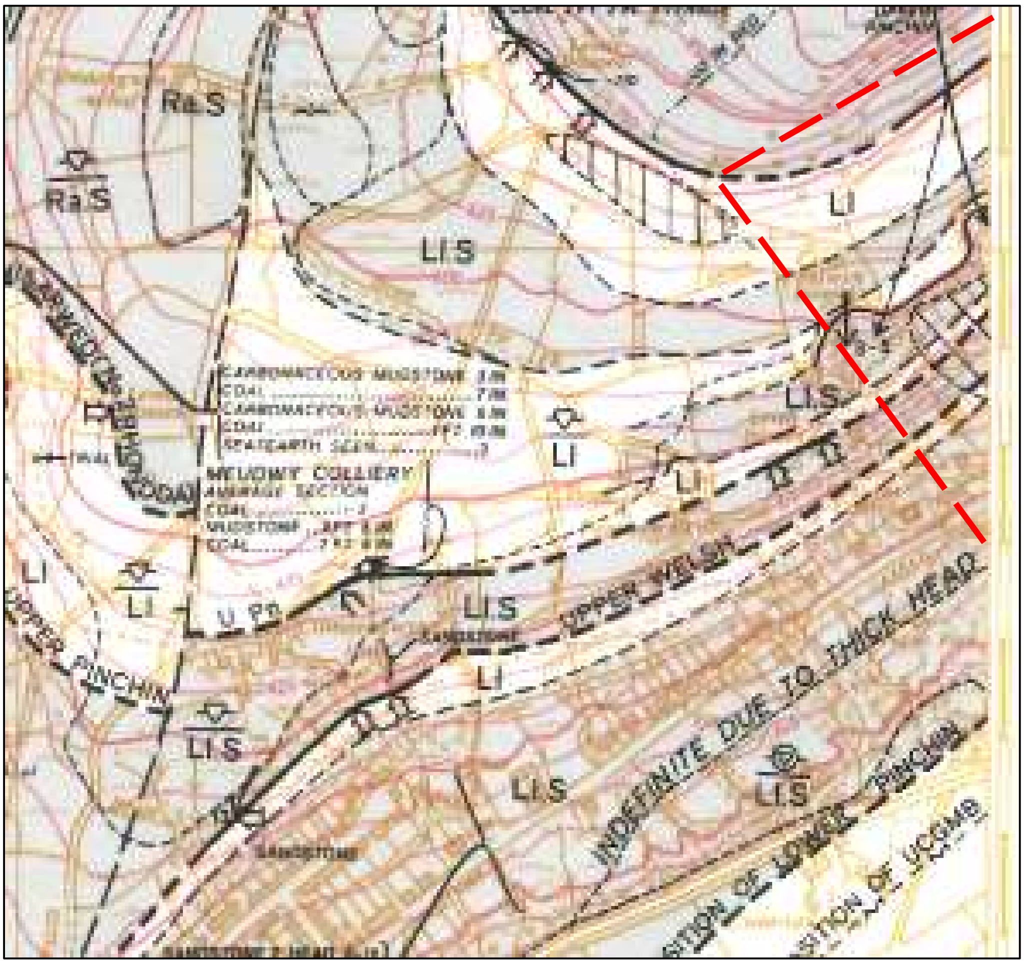

Figure 2b: Geological Map SN70NW extract. Red line shows study area. (BGS licence number: C15/05 CSL) Not to scale

Study of the geological map and adjacent sheets has shown the potential for several other seams, between the No. 2 Rhondda and Lower Pinchin, which include the Paynes and the Pant Rhyd Y Dwr, however these are not mapped in the study area, they occur in the same sequence in nearby areas and they may or may not be present.

Both the 1:10,560 and 1:50,000 scaled maps of the area show no glacial or superficial deposits on the hill side above the school. However, Glacial Diamicton and Fluvioglacial deposits are shown in the Tawe valley and recent workings by ESP in the Tawe valley has shown Glacial Diamicton further upslope than mapped, and some covering of glacial deposits is likely, possibly to an elevation of about 120mOD.

2.5 Hydrogeology

The combination of the geological setting and topography of the study area will dictate the hydrogeology. Generally, as discussed in Section 2.1, the study area is situated on the eastern flank on Mynydd Allt-y-grug in the Tawe Valley and water will most likely drain to the river which lies at the base of the valley.

Simplistically, Mynydd Allt-y-Grug is formed by sandstone (Rhondda Member) that overlies a series of mudstones, siltstones and sandstones of the South Wales Upper Coal Measures.

The sandstone units will be relatively more permeable (secondary porosity) than the underlying relatively argillaceous rocks and to a certain extent, the argillaceous rocks will limit downward migration of groundwater. The bedding planes of these strata all dip gently about 3° to 5° toward the south.

Whilst groundwater will percolate downward, due to gravity and primarily via fracture flow; some groundwater could also flow along bedding planes and near horizontal fractures and thus there may be a small component of groundwater flowing out of the eastern side of Mynydd Allt-y-Grug, into the study area. Spring lines will likely form where more permeable strata overlies less permeable strata and several springs within the study area are noted to mirror the outcrop pattern.

Any worked coal seams will likely provide a preferential pathway for groundwater to drain, given the dip this will be primarily toward the south.

2.6 Past Coal Mining

As discussed in Section 2.5, the site is underlain by bedrock of the South Wales Upper Coal Measures, which contains several seams of coal (and bands of ironstone).

From the geological map, coal seams that were expected to out crop in the hillside above the school included the No.2 Rhondda, Upper Pinchin and Upper Welsh. Although not shown on the geological map for the study area, in the same sequence of rocks nearby, other coal seams are encountered, which include the Pant Y Dwr and Payne's.

Evidence from the geological maps, online Coal Authority viewer and geological memoirs suggests that the No.2 Rhondda and Upper Pinchin were worked extensively in the area.

The workings in the No.2 Rhondda and Upper Pinchin coal seams have results in colliery spoil being discarded, normally down slope of the adits or quarries where they were worked, and the historical maps show the location of the adits and associated spoil mounds.

It should be appreciated that the Coal Authority records are incomplete, partly because there was no statutory and mandatory requirement on colliery owners to survey and record the extent of mine workings until the Coal Mines Regulation Act of 1872. Therefore, given the potential age of the potential workings, no surveys may ever have been undertaken on them and therefore, the lack of records does not discount the possibility of workings. In addition, where records were kept, due to copying of plans through time is it not uncommon for the plans to contain plotting errors or replots of the same features, such as mine shafts and adits. Thus, where a high number of mine entries are located in a small area, it is possible that the seam feature is replicated, and this should be borne in mind when assessing their information.

2.6.1 Summary of Mining Information

The information obtained to date indicates a large amount of coal mining in the study area, it is likely that most of the mining concentrated upon the No. 2 Rhondda and Upper Pinchin. The workings in the No.2 Rhondda and Upper Pinchin are most noticeable when considering he historical maps and mining data, spoil from quarries and adits accessing these coal seams have been placed on the landscape above Godre'r Graig.

3 Hazard Identification and Risk Assessment

3.1 Introduction

A Landslide hazard and risk assessment for the study area, i.e. Godre'r Graig Village has been undertaken with collaboration with Steve Parry[2].

As discussed in Section 1, ESP have previously carried out a collaborative landslide hazard and risk assessment (Ref. 7234e.3221) for the terrain above Godre'r Graig School ("the School"), Godre'r Graig. This assessment follows on from the previous report, but only considers the risk to residential properties in Godre'r Graig, within the area outlined in Figure 3. Given that the consequences to the school of a landslide are significantly different than for residential houses, the landslide hazard and risk to the School has been excluded from this assessment (Section 3.7).

Risks to the school are not discussed in this report, but can be viewed in ESP reports referenced 7234e.3221 and 7234e.02.3302.

The Study Area is approximately 750m wide and extends upslope (northwest) for approximately 400m from Graig Road and downslope from Graig Road to the A4067. ESP have provided copies of historical maps, geological maps and aerial photographs. In addition, orthorectified aerial photographs (dated 2013 and 2014) and a DEM were purchased.

The landslide hazard and risk assessment comprises three phases:

1. Phase One, an initial appraisal comprising an evaluation of historical data, aerial photography interpretation and initial engineering geomorphological mapping from available data (PEGS 2019b);
2. Phase Two, site specific engineering geomorphological mapping; and
3. Phase Three, a final appraisal of the landslide hazard and risk for the residential properties.

The information below comprises the results of the Phase Three work.

---

[2] Co-editor of: Developments in Engineering Geology. Geological Society Special Publication. 2016.
Author of: Landslide hazard assessments: problems and limitations. Examples from Hong Kong. 2016.
Chair of the IAEG commission C25 'Use of Engineering Geological Models'.
Member of the European Federation of Geologists' 'Group of Experts' on Natural Hazards and Engineering Geology.
Member of the International Association of Geomorphologists' Working Group on Applied Geomorphological Mapping.

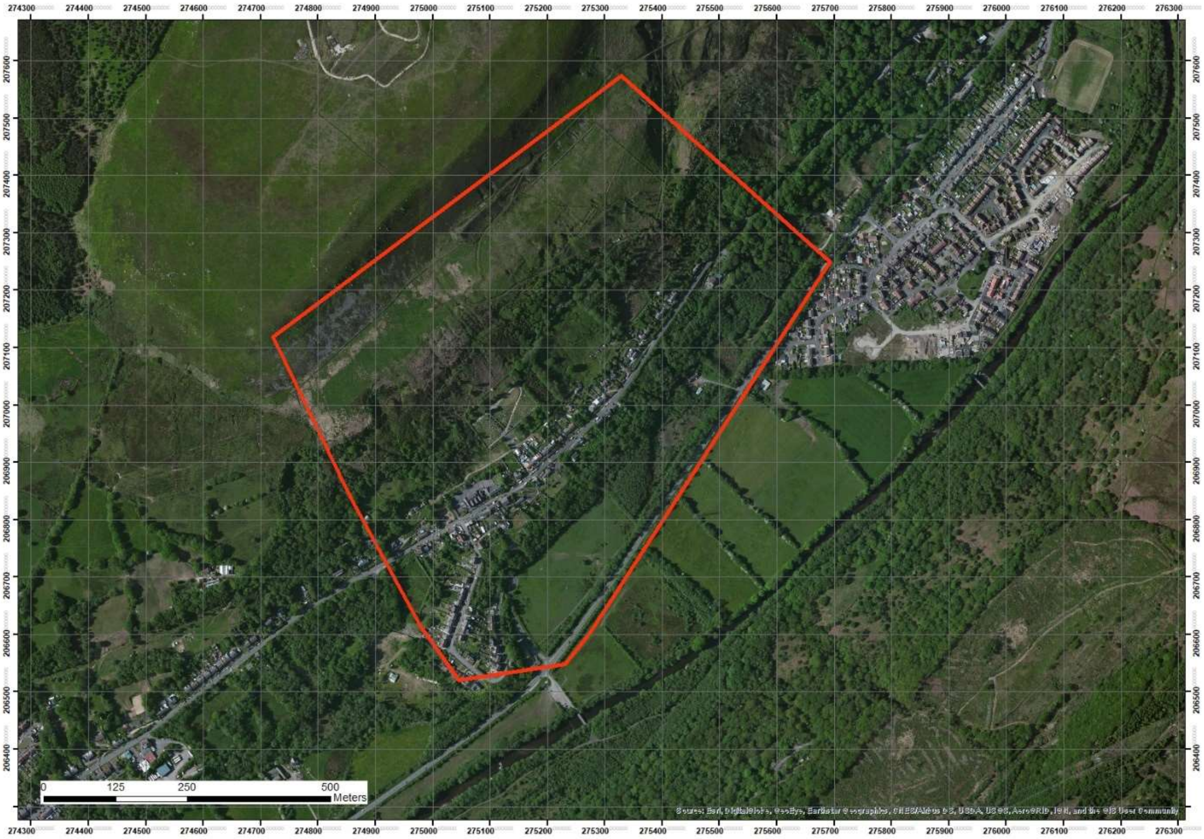

Figure 3: Study Area. Scale as shown.

3.2 Landslide Hazard and Risk

There are no UK standards for the assessment of landslide hazard and risk. However, Fell et al. (2008), reporting on behalf of JTC-1 (Joint Technical Committee on Landslides and Engineered Slopes, an IAEG, ISRM, ISSMGE collaboration exercise, i.e. all relevant international geotechnical societies) provides guidelines for landslide hazard and risk assessments. JTC-1 is broadly in line with AGS (2007) with minor modification for international practice.

The guidelines provide:

- Definitions and terminology for use internationally;
- Description of the types and levels of landslide zoning;
- Guidance on where landslide zoning and land use planning are necessary to account for landslides;
- Definitions of levels of zoning and suggested scales for zoning maps taking into account the needs and objectives of land use planners and regulators and the purpose of the zoning;
- Guidance on the information required for different levels of zoning taking account the various types of landslides;

- Guidance on the reliability, validity and limitations of the method; and

- Advice on the required qualifications of the persons carrying out landslide zoning and advice on the preparation of a brief for consultants to conduct landslide zoning for land use planning.

The guidelines also provide the following definitions:

Hazard — A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

Elements at risk —The population, buildings and engineering works, economic activities, public services utilities, other infrastructures and environmental values in the area potentially affected by the landslide hazard.

Vulnerability — The degree of loss to a given element or set of elements within the area affected by the landslide. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is (are) affected by the landslide.

Risk — A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability of a phenomenon of a given magnitude times the consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form. For these guidelines risk is further defined as: (a) For life loss, the annual probability that the persons at risk will lose their life taking into account of the landslide hazard, and the temporal–spatial probability and vulnerability of the person (b) For property loss, the annual probability of a given level of loss or the annualised loss taking into account the elements at risk, their temporal–spatial probability and vulnerability.

Zoning — The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk or applicability of certain hazard-related regulations.

The guidelines note that "*Qualitative methods are often used for susceptibility zoning, and sometimes for hazard zoning. When feasible it is better to use quantitative methods for both susceptibility and hazard zoning. Risk zoning should be quantified. More effort is required to quantify the hazard and risk but there is not necessarily a great increase in cost compared to qualitative zoning*".

Lee and Jones (2014) note that there are three broad types of risk estimation:

- Qualitative risk estimations are "*those where both likelihood and adverse consequences are expressed in qualitative terms. They are therefore highly subjective estimations*";

- Semi-quantitative risk estimations which are "*combinations of qualitative and quantitative measurements of likelihood and consequence*"; and

- Qualitative risk estimations (or quantitative risk assessments, QRA) which "*combine values of detriment with probabilities of occurrence. It must be noted that such an approach frequently does not produce a single answer*"

Whilst the AGS/JTC-1 guidelines were developed for hazard and risk zoning, i.e. assessing landslide hazard and risk for new developments, they are equally applicable for evaluating landslide hazard and risk to existing developments. Where appropriate, the AGS guidelines were used as the basis of this assessment.

AGS/JTC-1 guidelines suggest the following stages for a landslide hazard and risk assessment:

- Hazard identification which comprises classification of landslides, extent of landslides (area and volume), travel distance of landslides and rates of movement;
- Frequency analysis based on an estimation of frequency, historic performance, or related to initiating events;
- Consequence analysis comprising elements at risk, temporal probability and vulnerability; and
- Risk calculation.

Once these steps have been undertaken an evaluation of risk can be undertaken and risk mitigation.

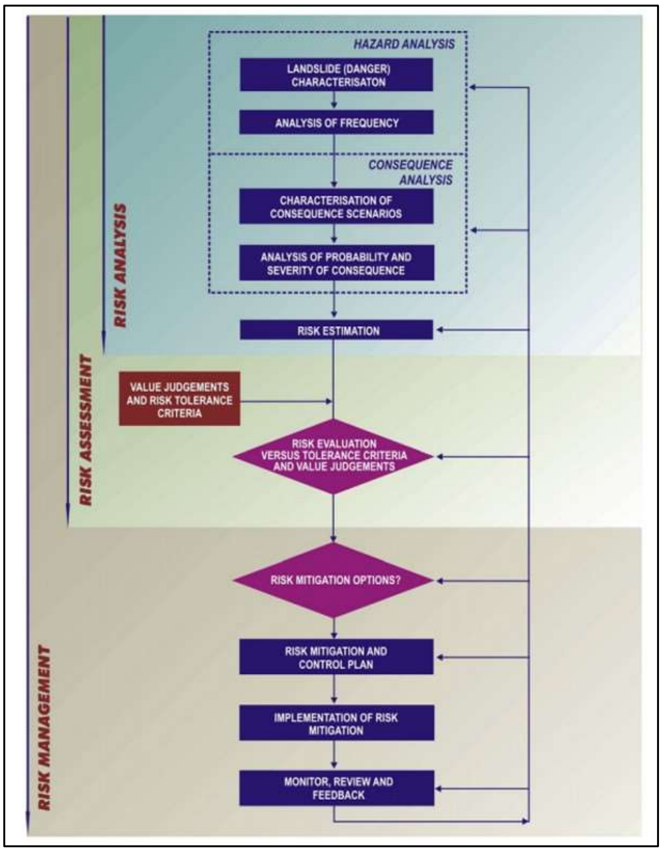

Figure 4: Framework for landslide risk management (Fell et al, 2008)

3.3 Landslide Classification

Landslides are typically classified in terms of material type (rock, debris, earth) and movement type (fall, topple, slide, flow) following the definitions of Cruden & Varnes (1996). However, landslides can be complex processes. For example, a landslide may initiate as a slide, disaggregate and become a debris avalanche, enter a drainage line and become a debris flow, enter a flatter area, deposit the coarse material but continue downstream as a debris flood. Hungr et al., 2001 noted problems with the use of the flow terminology as proposed by Cruden & Varnes (1996) and proposed amended terminology

Consequently, where a landslide is interpreted as involving "a rapid to extremely rapid flow of saturated non-plastic debris in a steep channel" (Hungr et al., 2001), it is classified as a debris flow, where it is interpreted as involving "very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope without confinement in a channel." (Hungr et al., 2001), it is classified as a debris avalanche. As noted by Hungr et al., 2014 "the practical consequences of the distinction between debris flow and debris avalanches are obvious. A debris flow hazard study begins with the definition of the path and at least the lateral limits of the deposition area (fan). The path and the debris fan can be expected to contain evidence of past occurrences which can be used to derive information on magnitude and frequency. Debris avalanche studies, on the other hand, must examine tracts of steep slopes, many segments of which may not have experienced debris avalanches during the observable past".

3.4 Hazard Identification

3.4.1 Elements at Risk

The elements at risk are the residential buildings (temporally and spatially fixed) and the occupants of the residential buildings (temporally and spatially variable). The residential buildings vary in both age (some predating the earliest available (1877) historical map to recently constructed) and type of construction (two-story detached, semi-detached and terraced houses and single-story bungalows).

As discussed in Section 1, this report does not evaluate risks to the school, this is considered in separate assessments (ESP report refs. 7234e.3221 and 7234e.02.3302). Consideration to users of the Cemetery is provided in Section 3.7.

3.4.2 Previous Landslide Assessments

The most significant landslide in the area is the large complex landslide (Godre'r Graig Landslide) to the east of Godre'r Graig village, the right flank of which lies just within the eastern boundary of the Study Area. Movement of this landslide in the late 1950's and early 1960's, led to the closure of Graig Road (A4068) and the abandonment of the village of Pantyffynnon (Halcrow 1987). This landslide was studied by Halcrow (1987). However, that study does not extend beyond the boundary of the landslide itself. The right flank of the Godre'r Graig Landslide lies within the Study Area. However, there are no residential facilities in the area of the landslide, although two properties are located close to the boundary of the landslide.

The British Geological Survey (BGS) geological map sheet SN 70 NE records an area of "shallow slips" above Graig Road in the central part of the Study Area.

A search of NPTCBC records by ESP has not located any additional landslide information in the Study Area.

A landslide hazard and risk assessment for the school was undertaken in 2019 ref. 7234e.3221.

3.4.3 Historical Maps Review

The earliest historical map (1877) shows three quarries upslope of Graig Road, with spoil extending down slope from the quarry floor. All three quarries were extended by 1898-9.

Numerous "old coal levels" (adits) are shown on the earliest maps (1877) trending northeast-southwest at approximately 170mOD, just downslope of the quarry locations, aligning with the position of the Upper Pinchin coal seam as shown on the geological map.

Between 1918 and 1960 additional disused adits are recorded, again aligning with the position of the Upper Pinchin coal seam as shown on the geological map.

In 1918 a fourth quarry is shown located in the northeast of the Study Area between the outcrop of the Upper Pinchin coal seam and Graig Road.

3.4.4 Aerial Photograph Interpretation

An Aerial Photograph Interpretation (API) of historical aerial photographs has been undertaken. The photographs evaluated are documented in Appendix B.

The API was carried out using a Sokkisha stereoscope with x3 binocular attachments. The API was made on a basis of shape, pattern, size, tone/colour and texture together with morphographical position.

The API has two key aims:

- to allow initial engineering geological and engineering geomorphological mapping of the Study Area, and
- to evaluate for any evidence of previous landslides in the study are and, if present, generate a site-specific landslide inventory.

The aerial photographs were imported into a Geographical Information System (GIS) using the software ArcGIS and the images orthorectified to assist with the locations of features observed in the API.

The API and initial mapping (ESP 2019) formed the basis for the field mapping undertaken on 21st January 2020.

3.4.5 Engineering Geomorphological Map

The engineering geomorphological map is shown in Figure 5. This is based on a combination of API as well as field mapping undertaken previously as part of the assessment of Godre'r Graig School (ESP 2019) as well as the recent mapping undertaken on 21 January 2020.

The Study Area shows a distinctive "stepped" topographical profile, largely reflecting the underlying geology.

The highest terrain is formed by Mynydd Allt-y-grug which rises to a height of 338mOD. The summit is relatively gently sloping. A sharp convex break in slope is present at approximately

292mOD associated with a linear rock outcrop below which the terrain is steep (25-30°) and associated with limited vegetation and a talus drape. A dry stone wall is present at the toe of the talus slope and there was no evidence of damage to the wall from rock fall nor any evidence of repairs resulting from rock fall. According to the published geological map Mynydd Allt-y-grug and the steep terrain is underlain by Rhondda Sandstone.

Plate 1: Rock outcrop (Rhondda Sandstone) with the associated talus slope below.

Larger individual blocks (rock falls) are present extending further downslope from the talus drape, the largest of which is 0.2m x 3.0m x 2.0m. It is considered that the generation of large rock falls was probably associated with periglacial conditions at the end of the last ice age (approx.. 11,700 years BP) and consequently the main trigger for rock fall processes is no longer active. Smaller falls of cobble size blocks may still occur although again this process would have predominantly been active during periglacial conditions.

The base of this steeper terrain is marked by a district concave break in slope which corresponds to the outcrop of the No 2 Rhondda coal seam at the base of the Rhondda Sandstone. Coal workings are evident in the form of adits and associated spoil in the northeast of the Study Area (Plate 2), with the working of the seam evident in the 1973 and 1975 aerial photographs.

Plate 2: Coal spoil tips associated with the working of the No 2 Rhondda coal seam

Below the No 2 Rhondda the Llynfi Beds are present, comprising alternating sandstone and mudstone resulting in stepped topography. The published geological map shows the Upper Pinchin Coal seam as outcropping at approximately 178mOD. This is associated with over steep, anthropogenically modified terrain as well as a series of adits reflecting its historical working.

Four abandoned quarries also present above the outcrop of the Upper Pinchin. Three are shown on the earliest historical maps (1877). A fourth appears in 1918 between the Upper Pinchin and Graig Road. All four quarries are associated with spoil which extends down slope from the quarry floor.

The Llynfi Beds, exposed at Quarry 1, comprise weak to medium strong, thinly bedded, dark grey, partially weathered to unweathered, micaceous sandstone. Bedding dips at 20/185. Two additional discontinuity sets were observed 84/274 with an approximately 1m spacing and 74/018 with a spacing of approximately 5m. The latter set is dilated with an aperture of up to 10cm (Plate 3), reflecting either the effects of mining or cambering.

Plate 3: Bedding dipping from left to right (20/185) the rock face is formed by joint set 84/274 and the dilated joint set is formed by 74/018.

***Plate 4:** Recently deposited spoil from work in Quarry 1.*

Recent works have been undertaken in Quarry 1 with an improved access road constructed. Spoil from this work has been end tipped below the quarry entrance (Plate 4).

Based on the exposure in Quarry 1, the spoil at this location is likely to comprise interlocking, angular and tabular boulders and cobbles of weak to medium strong sandstone (Plate 5). The spoil associated all the quarries is associated with very dense vegetation, especially brambles limiting access.

Plate 5: Typical spoil exposed in the northwest quarry

ESP undertook additional ground investigation, including vegetation clearance, in the spoil associated with Quarry 4 above Godre'r Graig School in November 2019. This allowed additional mapping to be undertaken. The interpreted toe of the quarry spoil is at approximately 125mOD which coincides with a natural convex change in slope. A series of springs are present at this level suggesting lower permeability material is present, possibly a mudstone layer within the Llynfi Beds. The lower part of the spoil tip extends upslope to approximately 140mOD and is only slightly steeper than the natural ground surface (28° compared with 25° in the natural terrain). The lower part of the spoil tip is associated with mature trees.

A shallower slope (15°) is present in the spoil to approximately 150mOD where what appears to be the main spoil tip is present sloping at 40°.

The surface of the tip is associated with angular cobbles of sandstone. No evidence of distress or perched groundwater was noted.

3.4.6 Landslide Inventory

The eastern end of Graig Road was inspected where the interpreted boundary of Godre'r Graig Landslide is located but there was no evidence of distress in the road/footpath and associated retaining walls.

The "shallow slips" recorded on the geological map are not evident on the historical aerial photographs. However, two areas interpreted as being associated with hydrophilic vegetation have been interpreted in the 2013 orthophotograph (Figure 6).

Similar features are evident in the 2013 orthophotograph between the No. 2 Rhondda and Upper Pinchin coal seams in the northeast of the Study Area which also coincides with two possible landslides in the 1952 aerial photographs. However, these areas were inspected and are considered to be related to hydrophilic vegetation with no evidence of landslide processes (Plate 6).

Figure 6: Enlargement of 2013 Orthophotography showing possible landslides identified in the area of "shallow slips" recorded on the geological map.

Plate 6: Hydrophilic vegetation below the No 2 Rhondda Seam in the northern part of the study area. No evidence of landslide processes.

A tension crack is present in the 1978 aerial photographs above the No. 2 Rhondda coal seam, working of which is evident in the 1973 and 1975 aerial photographs. This was inspected and is up to 0.75m wide and 2m deep, extending approximately 40m, and is likely to be the result of localised mining induced instability (Plate 7). At the location of the No 2. Rhondda Seam, a series of former adits are present which are associated with landslides. However, the regolith is thin and the rock mass competent and as a result the landslides are shallow, of small volume (<10m^3) and have limited run out (Plate 8).

Plate 7: Tension crack above the No2 Rhondda coal seam likely to be the result of localised mining induced instability.

Plate 8: Shallow, small (<10m^3) landslides above former adits in the No 2 Rhondda Seam.

Numerous localised areas of high reflectance are present on the earliest aerial photographs coinciding with the locations of the adits shown on the historical maps and the outcrop of the Lower Pinchin coal seam. The majority of these area are likely to represent disturbed ground associated with the working of the coal seam and not landslides (Figure 7).

Figure 7: Extract of the 1945 Aerial photograph showing high reflectance associated with adits working the Upper Pinchin coal seam

However, a tension crack is evident in the 1997 photographs associated with a former adit associated with the Upper Pinchin. Movement appears to be intermittently ongoing, with the tension crack being larger in extent in the 2013 orthophotograph (Figure 8). The landslide is associated with a drainage line from up slope. Whilst dense vegetation and steep slope precluded a detailed inspection, no rock outcrop was observed and a series of tension cracks are present upslope of the main scarp.

Figure 8: Tension crack (circled) above former adit location

Additional features identified as possible landslides and depression in the 1952 aerial photographs are associated with relatively deep (2-3m high) depressions which are probably the location of former adits (Figure 9). The high reflectance evident in the 1952 aerial photograph is considered to reflect localised instability associated with the over steep adit sides. The longest run out based on the API is approximately 27m.

Figure 9: Extract from 1952 photograph with possible landslides circled

In the 2014 orthophotograph a recent (post 2013) landslide has occurred (Figure 10), again close to a former adit location. The run out from this landslide is 70m with an angle or reach of 26°.

Figure 10: 2014 Landslide

It would appear that the rock mass associated with the Upper Pinchin is relatively weak and the over steep ground associated with the former adits acts as a loci for slope movement which can ultimately result in complete detachment and landslide run out.

The area of "shallow slips" recorded on the geological map comprises a series of shallow depressions associated with springs and hydrophilic (marshy) vegetation. A small cut slope 0.2m – 0.3m high, associated with a former tramway crosses the toe of these features. This exposes of clayey silt with occasional sub angular, medium to coarse gravel which has been interpreted as colluvium. There is no evidence of movement in this cut slope. Shallow (<0.2m) earthslides/earthflows may be associated with these depressions. This terrain extends across the Study Area to the southwest and instability, in the form of a distressed road (Plate 9) and a shallow depression, was noted within the cemetery at approximately the same level. At the rear of the School there was no evidence of landslides or distress. However, terracettes suggesting very shallow soil movement and wet ground is present.

Plate 9: Distress evident in the upper part of the cemetery.

3.5 Hazard Types

Based on the API and the previous assessment for the School (ESP 2019) four possible hazard types have been identified (Figure 11):

- Hazard type 1 - Rock fall - possible structural damage, impact on people;
- Hazard Type 2 - Debris avalanche/boulder fall initiating from spoil – impact loading on structures, impact/burial of people outside building, burial of people inside buildings (ground floor) if sufficient volume;
- Hazard Type 3 - Debris avalanches initiating from over steep slopes, in particular adits, associated with working of the Upper Pinchin – impact loading on structures,

impact/burial of people outside building, burial of people inside buildings (ground floor) if sufficient volume; and

- Hazard Type 4 - Shallow earth slides, slow ground displacement leading to vertical or lateral displacement, or undermining of structures and infrastructure.

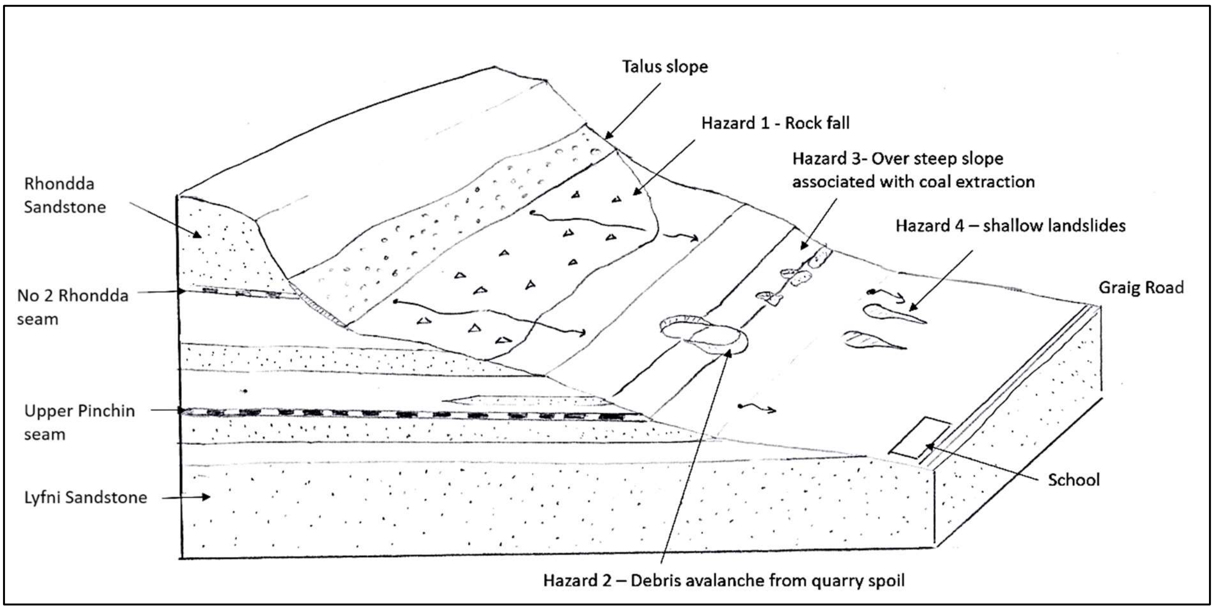

Figure 11: Conceptual Engineering Geological Model of site from API

3.5.1 Hazard Type 1

Rock fall initiating from outcrops of the Rhondda Sandstone typically at 260-270mOD. Relatively small, typically cobble size, more frequent, rock falls have led to the development of a talus slope. Larger blocks have travelled further with the furthest travelled located at 192mOD, approximately 180m horizontal distance from the outcrop. There was no evidence of damage or repairs to the wall at the toe of the talus slope resulting from rock fall. Movement velocities of rock fall tend to be rapid ($5x10^{1}$ mm/s to $5x10^{-1}$ mm/s i.e., 1.8m/hr to 3m/min). If rock falls reach the elements at risk these may result in a risk to life where individuals are outside. Residential buildings are likely to offer a high degree of protection and therefore rockfall is unlikely to pose a risk to life to people within the properties. Any structural damage from rockfall is likely to be limited.

3.5.2 Hazard Type 2

Impact from debris avalanche initiating from the spoil associated with the former quarries and collieries.

Debris avalanches are likely to be rapid to very rapid ($5x10^{1}$ mm/s to $5x10^{3}$ mm/s i.e., 3m/min to 5m/sec). The boundary between rapid and very rapid is approximately the average human running speed. If the debris reaches the residential properties, it may result in a risk to life where individuals are outside the rear of the property. If the volumes are relatively small, the debris may only result in limited structural damage. If larger volumes of debris are involved this may result in more significant damage and possible risk to life to those inside the property.

3.5.3 Hazard Type 3

Impacts from debris avalanches originating from the over steep slope associated with the working of the Upper Pinchin seam.

Associated movement velocities with debris avalanches are likely to be rapid to very rapid ($5x10^1$ mm/s to $5x10^3$ mm/s i.e., 3m/min to 5m/sec). The boundary between rapid and very rapid is approximately the average human running speed. If the debris reaches the residential properties, it may result in a risk to life where individuals are outside the rear of the property. If the volumes are relatively small, the debris may only result in limited structural damage. If larger volumes of debris are involved this may result in more significant damage and possible risk to life to those inside the property.

3.5.4 Hazard Type 4

Shallow earth slides. These were tentatively identified from API in the area of "shallow slips" noted on the geological map. Associated movement velocities are likely to be very slow to slow ($5x10^{-7}$ mm/s to $5x10^{-5}$ mm/s i.e., 1.6m/year to 16mm/year). Based on the field mapping these appear to be limited in depth. The limited depth and low movement velocities are unlikely to pose a risk to life and any structural damage is likely to be limited.

Figure 12 shows the location of each hazard type.

3.6 Hazard Assessment

When estimating the probability of a landslide occurring there are two fundamentally different approaches; the frequentist and the degree of belief (Lee and Jones 2014). The frequentist approach involves the statistical analysis of an inventory of landslide events in a particular area over time. In comparison, the degree of belief involves making a judgement based on available information and experience. Given the limited landslide inventory this assessment is largely based on a degree of belief approach to assign probabilities to landslides in an explicit and consistent manner. Such an approach is inevitably subjective.

The landslide hazard itself comprises two distinct components, the probability of a landslide occurring and the probability that the detached material will impact of the elements at risk (i.e. the residential buildings).

3.6.1 Hazard Type 1 - Rock fall initiating from outcrops of the Rhondda Sandstone

Large rock falls potentially pose a hazard to the residential buildings. However, it is considered that the majority of rock falls, in particular larger (boulder size) rock falls, were associated with periglacial conditions occurring at the end of the last ice age (approximately 11, 700 years BP). Therefore, the main triggering process for large rock falls is no longer active. Consequently, a likelihood of occurrence (i.e. new detachments) of detachment of 1,000 to 10,000 years has been assumed.

The boundary of the residential buildings are over 400m horizontal distance from the outcrop, i.e. over twice the distance of the furthest observed boulder from the outcrop. Consequently, the probability of a detached rock block reaching the residential buildings is considered to be small and a probability of 0.01 has been assumed. This suggests a likelihood of impact of >10^{-4} i.e. "unlikely" (AGS, 2007).

Small-scale (cobble size) detachments are likely to still occur, potentially annually. However, these are of limited mobility. Consequently, rock fall associated with small-scale rock blocks is not considered to be a hazard to the residential properties.

3.6.2 Hazard Type 2a - Impact from debris avalanche initiating from quarry spoil

In limited exposures the spoil appears to comprises interlocking, angular and tabular boulders and cobbles of weak to medium strong sandstone. On Quarry Spoil Tip 2 in areas of vegetation clearance the surface in part has a covering of loose, angular, cobble sized sandstone fragments.

There was no evidence of landslides or slope deformation associated with the quarry spoil from either the API or the field mapping. The approximate distance between the toe of the quarry spoil and the closest residential buildings varies from 54m to 180m.

There is very limited information of failure rates of quarry spoil tips. The Mineral Planning Guidance Note 5 2000 (subsequently superseded) notes that "Of the 110 "falls of ground" accidents, one third resulted from falls from mineral stockpiles, usually during reclaim of mineral for processing or sale, but none have been attributed to the collapse of a spoil heap or lagoon. Tip instability is, therefore, not a major source of accidents in British quarries". The document however notes that "nevertheless, there have been, on average, about 4 reportable dangerous occurrences per year involving insecure quarry tips". A dangerous occurrence with respect to tips is defined as "Any event (including any movement of material or any fire) which indicates that a tip to which Part 1 of the 1969 Act applies is or is likely to become insecure" (UK Government, 2013). As such it does not necessarily equate to a landslide.

The BGS note that there are over 2000 active quarries currently in the UK, assuming as a minimum one spoil tip per quarry suggests an annual occurrence rate of 0.2% (4/2000) or an implied indicative recurrence period of 500 years.

However, this is related to working tips and active stockpiles. Furthermore, as noted above, the statistics do not necessarily relate to a landslide. As such this is considered to be a very conservative estimate of failure. Consequently, an assumed probability of detachment of 5,000 years has been adopted, i.e. 1 order of magnitude lower.

There is limited data available for run out and so data for debris avalanches from Hong Kong has been adopted (Figure 13). Assuming the landslide is between 100m^3 and 500m^3 suggests a maximum run out of 23° with 90% stopping by 27°. Landslide run out data from the Pantteg landslide hazard assessment (PEGS, 2018) is also in Figure 13. These failures primarily involved colliery spoil. Based on this data It has been assumed that the probability of run out will be 1.0 for 27° or more, 0.1 for 27°-23°, 0.01 for 23°-20° (20° being the longest recorded run out) and 0 for <20°.

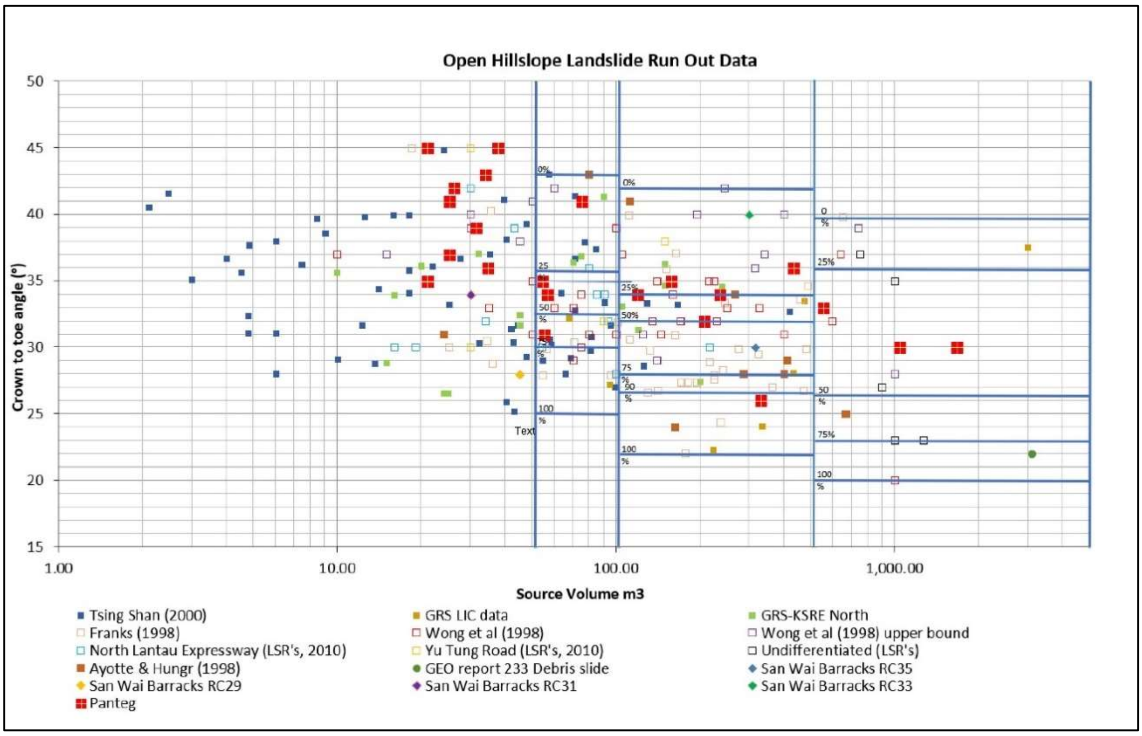

Figure 13: Landslide runout data from Hong Kong together with run out data from Pantteg (PEGS, 2018)

3.6.3 Hazard Type 2b - Impact from debris avalanche initiating from colliery spoil

The Mineral Planning Guidance Note 5 (2000) notes that "since the Aberfan disaster in 1966, the coal mining industry has had a similarly good record with only two accidents, both of which followed excavation of the toe of a previously stable closed tip". The document however notes that "nevertheless, there have been, on average, about 5 reportable dangerous occurrences per year involving coal mine tips". However, these occurrences occurred at working mines.

The Aberfan landslide is the UK's worst landslide disaster in which 116 children and 28 adults were killed. It comprised a debris avalanche of over 100,000m^3 of end tipped colliery waste which flowed over 600m. One key factor was the end tipping of waste over springs. Siddle et al. (1996) state that there were 18 similar events between 1898 and 1966. Most were associated with active tipping faces and one four years after abandonment and note that "the occurrence of rapid failures is shown to mirror the development of the coal fields but has ceased largely as a result of legislation to improve tipping practice which was enacted following Aberfan". No similar events have occurred since 1966.

There is very limited data on which assess the probability of failure of colliery waste. The tips themselves in the Study Area are limited in both extent and volume. Furthermore, there is no evidence that any of the tips were placed over springs. Consequently, it has been assumed that the probability of detachment is similar that of failure of quarry spoil, i.e. an assumed probability of detachment of 5,000 years has been adopted.

Landslide run out data from the Pantteg landslide hazard assessment (PEGS, 2018) is also in Figure 13. These failures primarily involved colliery spoil. One of these data points relates a debris avalanche which occurred in 1987 involving colliery spoil probably placed over a former spring. The 1987 landslide was interpreted as having two components; a translational landslide with an estimated volume of 1000m^3, a horizontal run out of 60m and travel angle of 30° and; a debris avalanche with an estimated volume of 300m^3, a horizonal run out of 100m and a travel angle of 26°. Despite involving a component of flow and presumably having a relatively high fines content the landslide runout plots within the overall data set, suggesting the empirical relationship is also applicable to relatively small landslides involving colliery waste where flow is not a component of movement.

Based on this data It has been assumed that the probability of run out will be 1.0 for 27° or more, 0.1 for 27°-23°, 0.01 for 23°-20° (20° being the longest recorded run out) and 0 for <20°.

The exception to this is Colliery Tip 5 in the northeast of the Study Area which has been incised by a drainage line, resulting in exposed colliery spoil standing at approximately 80°. The drainage line at this location is incised and therefore there is the possibility of small (<100m^3) debris flows to be generated. However, the drainage line intersects Graig Road where it is closed to vehicle traffic and pedestrian usage is probably low, suggesting the hazard is limited.

3.6.4 Hazard Type 3 - Impacts from debris avalanches originating from over steep slopes associated with the working of the Upper Pinchin seam

There is no evidence of instability associated with the over steep slope from either API or field inspections. However, based on the API and field inspections there is evidence for landslides (in the 1952 and 1997 aerial photographs and 2014 orthophotograph) associated with former adits, with a maximum interpreted run out of approximately 70m. This suggests a minimum return period of 10s to 100s of years. The closest distance between the adits and the residential buildings is approximately 160m, i.e. over twice the furthest runout observed.

3.6.5 Hazard Type 4 - Shallow earth slides

Based on the site mapping these features appear to be relatively shallow (<0.2m) earthslides/earthflows. These are likely to reactivate during periods of intense rainfall, with return periods in the range of years to 10s of years. However, the likelihood of runout run out beyond the mapped extent is considered to be very low.

3.7 Risk Assessment

Based on the API and field inspection there is evidence of very localised, possibly relatively recent, landslide movement in the Study Area. However, there is no detailed information on the age and extent of the different landslide types. As a result, it is not possible to undertake a detailed quantitative landslide assessment for all elements at risk. Consequently, a qualitative assessment of both hazard and risk has been undertaken largely based on a degree of belief approach.

The AGS (2007) provide a methodology for the qualitative assessment of risk to property and this has been adopted for the identified hazard types, as see below in Tables 1 to 4. Given that the consequences to the school of a landslide are significantly different than for residential houses, the landslide hazard and risk to the School has been excluded from this assessment. The risk levels are summarised in Table 5 and the elements at risk shown on Figure 14.

Table 1 provides a qualitative measure of likelihood and Table 2 presents a qualitative measure of consequences.

Table 1: Qualitative Measures of Likelihood

Approx. Annual Probability		Implied Indicative Landslide Recurrence Interval (years)		Description	Descriptor	Level
Indicative Value	Notional Boundary					
10^{-1}		10		The event is expected to occur ever the design life	Almost Certain	A
	5x10^{-2}		20			
10^{-2}		100		The event will probably occur under adverse conditions over the design life	Likely	B
	5x10^{-3}		200			
10^{-3}		1,000		The event could occur under adverse conditions over the design life	Possible	C
	5x10^{-4}		2,000			
10^{-4}		10,000		The event might occur under very adverse circumstances over the design life	Unlikely	D
	5x10^{-5}		20,000			
10^{-5}		100,000		The event is conceivable but only under exceptional circumstances over the design life.	Rare	E
	5x10^{-6}		200,000			
10^{-6}		1,000,000		The event is inconceivable or fanciful over the design life.	Barely Credible	F

Notes:
1. The above table is adapted from the AGS 2007 Appendix C tables.

Table 2: Qualitative Measures of Consequence

Description	Descriptor	Level
Structure(s) completely destroyed and/or large-scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.	Catastrophic	1
Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could	Major	2

Description	Descriptor	Level
cause at least one adjacent property medium consequence damage.		
Moderate damage to some of structure, and/or significant part of the site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage.	Medium	3
Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works.	Minor	4
Little damage.	Insignificant	5

Notes:
1.The above table is adapted from the AGS 2007 Appendix C tables.
2.The table primarily considered risk to property.

The associated levels from Table 1 and 2 are then used in Table 3 to provide a qualitative risk ranking and Table 4 provides example implications for each risk ranking.

Table 3: Qualitative Risk Analysis Matrix

LIKELIHOOD	CONSEQUENCE (TO PROPERTY)				
	1 Catastrophic	2 Major	3 Medium	4 Minor	5 Insignificant
A – Almost Certain	Very High	Very High	Very High	High	Medium or Low[2]
B – Likely	Very High	Very High	High	Medium	Low
C – Possible	Very High	High	Medium	Medium	Very Low
D – Unlikely	High	Medium	Low	Low	Very Low
E - Rare	Medium	Low	Low	Very Low	Very Low
F – Barely Credible	Low	Very Low	Very Low	Very Low	Very Low

Notes:
1.The above table is adapted from the AGS 2007 Appendix C tables.
2.Further consideration required, see AGS 2007 Appendix C tables for clarification.

Table 4: Risk Level Implications

Risk Level	Example Implications[1]
Very High	Unacceptable without treatment. Extensive detailed investigation, research, planning and implementation of treatment options essential to reduce risk to low. May be too expensive or impractical. Work likely to cost more than value of property.
High	Unacceptable without treatment. Detailed investigation, planning and implementation of treatment options required to reduce risk to low. Work would cost a substantial sum in relation to the value of the property.
Medium	May be tolerated in certain circumstances (subject to regulator approval) but requires investigation, planning and implementation of treatment options to

Risk Level	Example Implications[1]
	reduce the risk to low. Treatment options to reduce the risk to low risk should be implemented as soon as practicable.
Low	Usually acceptable to regulators. Where treatment has been required to reduce the risk to this level, ongoing maintenance is required.
Very Low	Acceptable. Manage by normal slope maintenance procedures.

Notes:
1.The above table is adapted from the AGS 2007 Appendix C tables.

3.7.1 Hazard Type 1 - Rock fall initiating from outcrops of the Rhondda Sandstone.

As discussed in Section 3.6.1, a return period of 1,000 to 10,000 years has been assumed for the probability of detachment of a large rock block. Furthermore, the likelihood of a detached boulder reaching the residential buildings is considered low (assumed to be 1% probability). This suggests a likelihood of impact of $>10^{-4}$ i.e. "unlikely".

The consequence of such impacts is considered to be limited damage to part of the structure i.e. minor consequences. This suggests a "low risk" to property from this hazard.

3.7.2 Hazard Type 2a - Impact from debris avalanche initiating from quarry spoil

As discussed in Section 3.6.2, an assumed probability of detachment of 5,000 to 50,000 years has been adopted. It has been assumed that the probability of run out will be 1.0 for 27° or more, 0.1 for 27°-23°, 0.01 for 23°-20° (20° being the longest recorded run out) and 0 for <20°.

This suggests a likelihood of impact of $>10^{-4}$ i.e. "unlikely" for slopes of 27° or more, $>10^{-5}$ i.e. "rare" for slopes of 27°-23° and $>10^{-6}$ i.e. "barely credible" for slopes of <23°.

The consequences of any impact is considered to be moderate damage to some of the structure i.e. medium consequences. This suggests a "low" to "very low" risk to property from this hazard depending on the slope angle.

3.7.3 Hazard Type 2b - Impact from landslides initiating from colliery spoil

As discussed in Section 3.6.2, an assumed probability of detachment of 5,000 to 50,000 years has been adopted. It has been assumed that the probability of run out will be 1.0 for 27° or more, 0.1 for 27°-23°, 0.01 for 23°-20° (20° being the longest recorded run out) and 0 for <20°.

This suggests a likelihood of impact of $>10^{-4}$ i.e. "unlikely" for slopes of 27° or more, $>10^{-5}$ i.e. "rare" for slopes of 27°-23° and $>10^{-6}$ i.e. "barely credible" for slopes of <23°.

The consequences of any impact is considered to be moderate damage to some of the structure i.e. medium consequences. This suggests a "low" to "very low" risk to property from this hazard depending on the slope angle.

The exception to this is Colliery Tip 5 in the northeast of the Study Area where there is the possibility of small (<100m^3) debris flows to be generated. However, the drainage line intersects Graig Road where it is closed to vehicle traffic and pedestrian usage is probably low, suggesting the risk is limited.

3.7.4 Hazard Type 3 - Impacts from landslides originating from the over steep slope associated with the working of the Upper Pinchin seam

There is no evidence of instability associated with the over steep slope from either API or field inspections. However, based on the API there is evidence for landslides associated with former adits. The desk study and field mapping recorded 18 adits associated with the Lower Pinchin seam of which three have been interpreted as potentially having landslides associated with them i.e. 16% chance over a 74-year period. As a result, a return period of 100 years has been assumed for the probability of detachment.

With the exception of a single property, (Property 31 which is 50m from the nearest adit) the nearest adit to the residential properties is 160m, i.e. over twice the furthest runout observed from API and a 0.01 probability of runout reaching the residential building has been assumed. This suggests a likelihood of impact of <10-3 i.e. "unlikely". With respect to Property 31, a probability of run out of 1.0 has been assumed. This suggests a likelihood of impact of <10-2 i.e. "likely".

The limited spatial extent of the adits suggest that landslide volumes would be limited and the debris thin and relatively wet. The consequences of any such impact is considered to be little damage i.e. insignificant consequences. This suggests a "very low" level of risk to property from this hazard with the exception of Property 31, which is considered to be "Low". However, given the condition of the access track, it would appear that Property 31 is not occupied.

3.7.5 Hazard Type 4 - Shallow earth slides

The nearest residential properties are over 70m from the interpreted toe of these landslides. These landslides are very slow to slow moving and appear to be limited in depth. As a result, they are not considered to pose any hazard to the residential properties.

Table 5: Summary Level of Risk to Property

Hazard Type	Likelihood Designation	Consequence Descriptor	Risk
Hazard Type 1 - Rock fall	Unlikely	Minor	Low
Hazard Type 2a - Landslides from quarry spoil	Unlikely to barely credible*	Medium	Low to Very Low*
Hazard Type 2b - landslides from colliery spoil	Unlikely to barely credible*	Medium	Low to Very Low*
Hazard Type 3 - Landslides associated with the working of the Upper Pinchin seam	Unlikely (likely for a single property)	Insignificant	Very low (low for a single property)
Hazard Type 4 - Shallow earth slides	N/A	N/A	N/A
Notes: *Depending on travel angle to element at risk			

Based on the above it has been assumed that the risk to residential properties to the south of Graig Road is very low.

3.7.6 Cemetery

No specific assessment has been carried out to assess the risk to members of the public using/visiting the cemetery. However, given that the cemetery will have a lower temporal usage than the surrounding residential houses, and that the shallow earth landslides are very slow to slow moving and appear to be limited in depth, risks to cemetery users is likely to be lower.

3.8 Risk Assessment Conclusions

There is insufficient data to undertake a quantified risk assessment. Consequently, a qualitative assessment based on AGS (2007) was undertaken primarily based on a degree of belief approach.

Based on the initial assessment, the landslide risk to the residential buildings in Godre'r Graig is considered to be low to very low.

Risks to cemetery users is likely to be lower than the risks to residential properties surrounding the cemetery.

Based on the initial assessment, the landslide risk is considered to be low to very low, which is normally "usually acceptable to regulators" (AGS, 2007).

This assessment is based on the conditions at the time of the assessment.

3.9 Uncertainties

The vegetation in the Study Area, in particular, in the areas of quarry spoil is extremely dense limiting both access and observations. Whilst site mapping has been undertaken this is limited in extent, largely being restricted to public access areas.

There is very limited information on the age and type of movement of landslides within the Study Area. Consequently, the assessment of the probability of detachment and run out used in the assessment are largely based on expert judgment.

4 Recommendations

The assessment has shown that there is a very low to low risk to residential properties in Godre’r Graig and no specific remedial or mitigation recommendations are considered necessary.

It may be prudent to undertake a review (at a return period to be determined) to check the assessment is still valid in coming months/years. If any movement is noted before this time period, then the assessment should be revisited immediately.

Recommendations in the ESP 2020 report associated with Godre’r Graig School (ref. 7234e.02.3302) are not replicated here and that report should be read in full.

5 References

AUSTRALIAN GEOMECHANICS SOCIETY. 2007 Practice Note Guidelines for Landslide Risk Management 2007. Volume 42 No 1 March 2007.

BRITISH GEOLOGICAL SURVEY (BGS). 2018. Website accessed April 2018.

BRITISH STANDARDS INSTITUTION (BSI). 2015. Code of Practice for Ground Investigation. BS5930:2015. HMSO, London.

CONWAY B W, FORSTER A, NORTHMORE K J, and BARCLAY W J. 1980. South Wales Coalfield Landslip Survey. Institute of Geological Sciences, London.

CRUDEN, D.M., VARNES, D.J., 1996. Landslide Types and Processes, Transportation Research Board, U.S. National Academy of Sciences, Special Report, 247:36-75.

EARTH SCIENCE PARTNERSHIP (ESP). July 2019. Godre’r Graig Primary School, Preliminary Landslide Hazard and Risk Assessment. 7234e.3221.

EARTH SCIENCE PARTNERSHIP (ESP). February 2020. Godre’r Graig Primary School, Preliminary Investigation and additional Assessment. 7234e.02.3302.

FELL, R., CORMNINAS. J., BONNARD, C., SAVAGE, W.Z., CASCINI, L., LEROI, E. 2008. Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning Commentary. Engineering Geology. 102 (58-98)

HALCROW (1987). Godre'r Graig and Pantteg Landslides. Report on Hazard Mapping. Lliw Valley Borough Council.

HUNGR, O., PICARELLI, L., 2014. The Varnes classification of landslides types, an update.

HUNGR, O., EVANS, S. G., BOVIS, M. J. & HUTCHINSON, J. N. (2001) A Review of the Classification of Landslides of the Flow Type. Environmental and Engineering Geoscience. Vol VII p221-238.

LAWRENCE, R. 2012a. The Collieries of the Swansea Valley General Area. *The South Wales Coalfield Series Book One Hundred.* Ray Lawrence, Blackwood.

LAWRENCE, R. 2012b. The Collieries of the Swansea City General Area. Ray Lawrence, Blackwood.

LEE, M. and JONES, D.K.C. 2014. Landslide Risk Assessment. Institute of Civil Engineers, London.

STRAHAN A. 1907. The Geology of the South Wales Coalfield, Part VIII, The Country around Swansea. Memoirs of the Geological Survey England and Wales, An Account of the Region Comprised in Sheet 247 of the Map. HMSO.

STRAHAN A. and CANTRILL T C. 1912. The Geology of the South Wales Coalfield, Part III, The Country around Cardiff. Second Edition. Memoir of the Geological Survey, England and Wales. Explanation of Sheet 263. HMSO.

WILSON D, DAVIES J R, FLETCHER C J N and SMITH M. 1990. The Geology of the South Wales Coalfield, Part VI, The Country around Bridgend. Memoir of the British Geological Survey, Sheet 261 and 262 (England and Wales).