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PENRHYN QUARRY REALIGNMENT 2019 - GEOTECHNICAL CONSIDERATIONS IN SLOPE DESIGN

For

WELSH SLATE LIMITED

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PENRHYN QUARRY REALIGNMENT 2019 - GEOTECHNICAL CONSIDERATIONS IN SLOPE DESIGN

1. INTRODUCTION

This report has been prepared for Welsh Slate Limited (Welsh Slate) which is now part of the Breedon Group, by GWP Consultants LLP (GWP) to accompany a planning application for the proposed realignment extension of the northwestern face of the South Quarry area at Penrhyn Quarry. GWP provides advice to Welsh Slate in respect of geological evaluation and geotechnical quarry design as part of the progressive quarry development review and to comply with the statutory requirements of the Quarries Regulations 1999 (Quarries Regulations).

This report summarises the relevant field data and findings of the geotechnical analysis undertaken for detailed excavated slope design at Penrhyn Quarry. Regulation 30 of the Quarries Regulations requires that all excavations and tips on an active quarry site are designed constructed, operated and maintained to ensure their safety. More specifically Regulation 33 requires that for the excavations at Penrhyn Quarry, a geotechnical assessment is required to regularly assess the overall slope stability and design. GWP act as geotechnical specialist on behalf of Welsh Slate and have collected the relevant data to determine the mechanisms of possible of slope failure. This is used to optimise slope design in order to maximise resources and maintain adequate access to the productive faces. The latest Regulation 33 review report for Penrhyn Quarry was issued by GWP in November 2018.

1.1 Location and historical background

The site is situated *c.* 1km to the southwest of Bethesda, Gwynedd, in North Wales centred at *c.* 2619000mE, 364650mN, and lies adjacent to the northwestern limits of the Snowdonia National Park.

The site is located on the northern flanks of Carnedd y Filiast which rises to 821mAOD to the south of the site, and to the west of Nant Ffrancon which runs to the northeast of the site. The quarry is split into two historic quarry areas which have progressed from northeast to southwest along the strike of the slate outcrop. The two quarry areas comprise:

The **North Quarry**, which includes large scale workings developed from the late 17^{th} century until 1989. These quarry workings are now flooded below the level of the outfall tunnel at *c* 121mAOD. The floor of the workings is believed to be at about sea level. Water flows through the outfall tunnel and ultimately runs into the Nant Ffrancon to the north of the site. The sidewalls are formed in a number of sub-horizontal benches (galleries).

The **South Quarry**, which includes the current working area, is developed at a higher elevation than the North Quarry and extends the system of benches or galleries which originally comprised the upper southwesterly benches of the North Quarry. The South Quarry currently has a floor at *c.* 255mAOD with the highest southeastern faces at an elevation of *c.* 457mAOD.

1.2 Geological setting

The geological setting is described in detail in the Geological Statement (GWP Report No. 191013) accompanying the realignment extension application and is summarised below.

The regional geological setting for Penrhyn Quarry is illustrated by the 1:50,000 Sheet 106 (Bangor) and 1:10,000 geological sheets SH 66NW and 66SW published by the British Geological Survey (BGS) and described in the accompanying memoir "Geology of the country around Bangor". The quarry has been developed within the Llanberis Slates Formation of Cambrian Age (550 million years old). This formation is formed by a thick sequence of multi-coloured (red, blue, purple, grey and green) silty mudstones and interbedded siltstones with a stratigraphic thickness of over 600m. At Penrhyn Quarry, the Llanberis Slates Formation is unconformably (and possibly fault) bounded to the north by the linear outcrop of the underlying Fachwen Formation, and the more extensive Padarn Tuff Formation. To the southeast, the slate belt appears to be conformably overlain by the coarse sandstones and grits of the Bronllwyd Grit Formation and the silty mudstones of the Marchlyn Formation. The South Quarry and proposed realignment extension area lie entirely within the Llanberis Slate Formation.

All of the strata in this area have been subject to low-grade regional metamorphism, which has induced a well-developed slaty cleavage within the fine-grained sediments. It is this regional cleavage (which at Penrhyn Quarry is sub-vertical, dipping at about 80° towards the southeast), which is exploited within the slate strata as it produces the ability for the strata to be easily cleaved into roofing slates. The slaty cleavage lies sub-parallel to the regional (northeast to southwest) fold axes developed in this area.

The slates themselves comprise fine grained meta-mudstones of varying colour which occasionally contain green stripes and/or elliptical spots. These often comprise more silty or sandy horizons and indicate the primary bedding features but are sometimes the consequence of reduction of iron minerals within the sediments (which more locally develop as the elliptical reduction spots).

The overall structure within the quarry comprises a large synclinal fold (which is bordered by a large anticlinal fold in the northeast of the North Quarry). The faulted axis of the syncline runs roughly northeast to southwest along the centre of the quarry areas. The trend of the fold axes is coincident with the cleavage[1].

The folded strata are transected by a number of sub-vertical faults, the majority of which also trend northeast to southwest although less frequent north to south cross faulting is also developed; in part the faults are thought to have nucleated off the cross cutting Ordovician dolerite dykes. The majority of faults are thought to have normal displacements to the south without any significant lateral displacement. The throw across individual faults is difficult to establish but is thought to be generally in the order of 5 to 40m. However, there is inferred to be significant vertical throws (of up to *c.* 150m) across 2 No. major 'boundary faults' which effectively sub-divide the South Quarry into 3 No. parallel geological and geotechnical domains from which similar slate product materials are currently derived.

Those parts of the sequence exposed within the quarry workings are seen to be affected by numerous sub-vertical dolerite dykes of Ordovician age which both follow and cross (obliquely) the trend of the main structural elements.

To the southwest of the current workings the solid strata are covered in glacial Boulder Clay materials of variable thickness. Observations of the advancing drift excavations to date prove the Boulder Clay to comprise a stiff clayey sandy gravel with cobbles and boulders. Inspection has shown there to be no evidence of any laterally extensive bedded weak units within it. Locally the materials reduce in clay content to comprise a dense sandy gravel with cobbles and boulders.

1.3 Geotechnical domains

Geological and geotechnical domains comprise areas of similar geological materials and or geological structure. In the South Quarry there are 3No. principal domains separated from one another by the large 'boundary faults' which trend sub-parallel to the direction of quarry face advance. They comprise:

The ***Hard Greys Domain*** (in the southeastern faces). This domain is separated from the adjacent Purple Domain by the Hard Grey Fault. The position of the Hard Grey Fault has been progressively mapped over the past 15 years to accurately define its position. The fault is inclined steeply towards the southeast. Bedding dips steeply (50-70°) towards the northwest. Localised intense folding in close proximity to the Hard Grey Fault is commonly observed.

The ***Purple Domain*** (the advancing southwestern faces). This is the area from which the slate block for roofing slate is derived. Bedding dips steeply (50-80°) towards the northwest. Geological mapping has shown that the majority of slate block in the upper benches is composed of the softer spotted purple slates and blue slate.

The ***Red and Blues Domain*** (in the northwestern faces). This domain is separated from the adjacent Purple Domain by the Purple Boundary Fault. This fault is also inclined steeply towards the southeast (78°/148°). The strata within the domain comprises the striped hard blue slate, red/plum coloured slate, sandstone and blue slates. Bedding dips are towards the southeast, *i.e.* in the opposite direction to the adjacent Purple Domain. The area is transected by numerous small faults of similar orientation to that of Hard Grey and Purple Boundary Faults. The synclinal axis running through the

1 Both are perpendicular to the direction of crustal shortening which gave rise to them.

South Quarry is faulted out by the Purple Boundary Fault such that bedding forms a sharp "V" on either side of the fault.

The slate rock is weathered to a depth of *c.* 55m in the more competent Hard Grey Domain and *c.* 55 to 65m below ground surface elsewhere within the Purple Domain. This currently coincides roughly with the William Parry bench level at *c.* 342 to 348mAOD.

2. GEOTECHNICAL INSPECTION AND DATA COLLECTION

Numerous visits to the site have been undertaken by GWP geotechnical engineers and surveyors between 2008 and 2019 in order to collect data for reserve/resource assessments and progressively map the exposed faces to monitor any change in structural setting. This data supplements data collected for the Regulation 33 Reports between 2000 and 2008.

2.1 Data collection and analysis

The orientation of the various discontinuity surfaces present within the rock mass has been derived by either direct measurement in the field or by indirect measurement using georeferenced photogrammetry (ShapeMetrix). The latter allows for remote access *via* computer rendering of co-ordinated stereo-photographs and for discontinuity measurement on surfaces which would previously have been inaccessible without roped access. The data collected from the various inspections is compiled in Appendix 1 and has been referenced by geotechnical domain.

The rock mass is cut by a number of discontinuity sets. These include:

i Bedding (often seen as a trace lineation in the face or colour variation or by the presence of thin siltstone or sandstone units and which frequently does not form a true discontinuity).

ii Cleavage (trace surfaces by which the slates are split).

iii Joint sets, of which there are a least 6 No. principal orientations with many more of random orientations (and which dictate overall slope gradients).

iv Faults (large through-going discontinuities across which there has been some displacement).

Drawing No. 19WPENP1901GC-1 comprises a combination drawing showing:

- The proposed final excavation void and the inferred position of the large boundary faults which define the principal geotechnical domains,
- A stereographic projection showing poles for all discontinuity data subdivided by discontinuity type,
- A series of stereographic projections for each geotechnical domain. The respective projections show discontinuity data collected from that domain only. Overlain on each of these projections is a kinematic overlay which is used to determine the likely slope failure mechanisms which could occur. The orientation of the overlays relate to the principal excavated face directions.

Analysis of the discontinuity data shows that there are a number (at least six) well developed discontinuity sets within the various domains. The extent to which some of the discontinuity sets are developed varies between domains. Further, there are a number of more locally developed discontinuity surfaces developed immediately adjacent to faults and dykes.

A summary of the discontinuity types (and site names for the relevant sets) and their average orientations for each geotechnical domain is set out in Table No.1.

As may be seen in the stereographic projections in Drawing No. 19WPENP1901GC-1, there is considerable scatter about each of the average orientations for the various discontinuity sets. All the discontinuities are laterally extensive in the order of 5 to 20m and locally >50m.

To summarise, a number of the discontinuity sets (Nos. 1, 3 and 4) dip towards the same general direction *i.e.* to the north-northwest. These sets are coincident with bedding strike (Set No. 1), and the general quarry alignment. Set No. 3, known as 'Foot Joints', are inclined at relatively shallow angles (dips of 8°-16°), whereas Set No. 4, known as 'Cropper Joints' are steeper dipping joints (dips of 27°-60°).

Cleavage strike is also roughly coincident with bedding strike for the Hard Greys and Purple Domains, but generally dips steeply (78°) in the opposite direction to bedding (*i.e.* into the southeast faces).

In the Red and Blues Domain there is an apparent second cleavage developed parallel to a set of shear joints which is oriented more towards the south (an azimuth of 170°). Cleavage is observed to be less well developed in the Hard Greys Domain (probably as a consequence of more silt sized materials within the mudstones which form these slates).

There are at least 2No. sub-vertical joints sets which are perpendicular to Sets No. 1-4 (but which dip either side of vertical) and which are best developed in the Hard Greys Domain.

In the Hard Greys Domain the major fault orientations run sub-parallel to Set Nos. 1-4. The Hard Greys Fault apparently strikes *c.* 050-230° and dips steeply into the faces; other fault sets to the southeast of the Hard Grey Fault strike *c.* 020-200°.

Geological mapping shows the Red and Blues Domain to be cut by numerous bedding strike parallel faults. These faults generally have throws of only a few metres but are seen to displace the cross cutting igneous dykes.

The quarry is transected by several dolerite igneous dykes. Not all are simple vertical features but are observed to split and follow sinuous pathways. The presence of the dykes locally deforms the cleavage in the adjacent strata.

As noted above, the bedding dips within the Hard Greys and Purple Domains are steeply towards the north-northwest. Bedding in the Red and Blues domain is generally to the southeast. The strata therefore comprises a faulted northeast to southwest striking syncline.

3. EXCAVATION SLOPE DESIGN

3.1 Impact on slope security and health and safety by adopting the proposed realignment extension configuration

The currently consented northwestern excavation limit in the realignment area has a *c.* 90m step to the southeast midway along it (see Drawing No. 19WPENP1910GC-2). The step in the excavation limit is a consequence of the presence of the sheepfold and previously identified possible archaeological features. The resultant narrowing of the quarry has significant impacts on slope stability, health and safety and winnable resources.

3.1.1 Impact on excavation security

The step in the excavation profile results in two internal corners and an external corner or "nose" at each bench level. The resultant faces of the "nose" propagate to the east with depth with individual faces on the "nose" also facing east. The introduction of an external corner into the excavation geometry introduces significant extra stability concerns because:

- The process of excavation causes significant stress relief and relaxation within the rock mass. On any external corner there are two free sides and the effects of stress relief are amplified compared to a straight face. The stress relief loosens the rock mass and increases the likelihood of larger structurally controlled failure and general unravelling leading to increased smaller scale rock fall.

  The faces of the "nose" face towards the east. The combination of persistent discontinuities within the rock mass means that faces in this orientation are prone to structurally controlled wedge and toppling instabilities[2] through the intersection of bedding (where present as a discontinuity surface) and jointing in the "Red and Blues" Domain and jointing and faulting in the "Purple" Domain. Such failures may result in the loss of a bench crest which would impact on anyone working on the bench below (as failure can occur sometime after formation). By straightening the faces to align the excavation with the strike of the strata, as will result by adopting the realignment extension, the potential for these styles of wedge and toppling failure is significantly reduced.

- There is an increase in unravelling on faces resulting in an increased rock fall hazard. Attempts to scale the loosened rock mass making up the "nose" can often be futile as an entire bench can easily be dug out when trying to find sound rock, resulting in a double height face which then presents an even greater rock fall hazard. Rock fall (often blocks of less than 10 tonnes)

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2 See further explanation in Section 3.2.

although relatively small in mass is the most frequent cause of fatalities in quarries involving falls of ground. The loosened rock mass increases the number of blocks which may fall and opens up joints allowing the ingress of water, reducing shear contact, all of which increases the propensity of blocks to detach from the face. Rock traps at the base of the faces may catch individual blocks but larger loose columns may topple across such traps.

Where the rock fall hazard is identified and wider rock traps are deemed necessary then bench widths have to be increased which widens the "nose" further, directly impacting on accessible roofing slate resources (see discussion in GWP Report No. 191013[3] comprising the supporting Geological Statement). Straightening the faces, as will result by adopting the realignment extension, will keep the rock mass relatively "tight" and the potential rock fall hazard is significantly reduced.

3.1.2 Impact on health and safety

Under Regulation 30 of the Quarries Regulations there is a requirement to ensure all excavations are designed to avoid movement which may increase risk to health and safety. As discussed above, by straightening the excavation boundary the increased hazards of structural failure and rock fall will be markedly reduced.

Under Regulation 13 of the Quarries Regulations there is a need to design haul roads to ensure plant can move safely along them. This includes removing wherever possible any sharp bends to improve visibility and avoiding travel around any external corners (developed by the "nose"). The step in the currently consented excavation boundary introduces sharp bends at both the internal corners and external nose. Straightening the excavation boundary eliminates the "nose" and both of these issues.

3.2 Geotechnical domains and potential failure modes

In order to establish what would be sustainable long term secure excavated slopes, a kinematic stability assessment of the advancing and final face orientations has been undertaken after the methods set out by Matheson[4]. The kinematic overlay shown on each of the stereographic projections in Drawing No. 19WPENP1901GC-1 allows for an assessment of potential for the three principal translational failure mechanisms which occur in stronger rocks *i.e.* planar, wedge and toppling failure.

A detailed kinematic assessment of each advancing face orientation[5] within each of the geotechnical domains is beyond the scope of this document, however a summary for the final face orientations in each domain is given below.

In general, the majority of planar and wedge instabilities on the steeper joints and cleavage would be eliminated by cutting the excavated face to 75°. Localised break-back is likely to occur on these joints and more specifically on the flatter cropper and bedding surfaces and the magnitude of this break-back depends on the structures prevalent within each geotechnical domain.

3.2.1 Hard Greys Domain

The analysis detailed below relates to the general domain face directions only *i.e.* for faces oriented towards 285°.

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3 GWP Report No. 191013 entitled "Penrhyn Quarry realignment 2019 - Geological Statement".

4 Matheson, G. D. 1983. Rock stability assessment in preliminary site investigations – graphical methods. TRRL Report 1039.

5 The development faces are generally *c.* 90° to final face orientations. These are considered in detail within the statutory reports produced for Welsh Slate to comply with the Quarries Regulations.

Instability mode	Potential	Notes
Planar	Likely on scatter about cropper (and bedding surfaces where present as discontinuities) when undercut in face. Minor localised break-back on other joints and shears.	Causes localised break-back on face; bench scale instability given the lateral persistence of the cropper joints and on bedding.
Wedge	Minor bi-planar wedges on scatter about average orientations.	Comprise smaller instances of the planar instability noted above.
Toppling	Possible across the face due to presence of more random vertical joints in combination with a basal release surface inclined out of face (toe joints).	Managed by face scaling.

The analysis detailed below relates to the general domain face directions only *i.e.* for faces oriented towards 312°.

Instability mode	Potential	Notes
Planar	Inevitable on cropper (and bedding surfaces where present as discontinuities) when undercut in face. Break-back on cleavage alone eliminated for faces of 75°. Expect additional localised break-back on other joints and shears.	Causes localised break-back on face; bench scale instability given the lateral persistence of the cropper joints and on bedding.
Wedge	Could occur as bi-planar wedges but will be coincident with and of less size/significance than the planar instability noted above.	Comprise smaller instances of the planar instability noted above.
Toppling	Inevitable due to presence of cleavage in combination with a basal release surface inclined out of face (both the toe and cropper joints).	The more open the cleavage then the higher potential for instability. Accelerated opening up of the cleavage may occur as a result blasting where expansive gasses open incipient cracks or with progressive weathering over time. Large scale failure possible where faults are exposed.

The size of failure that can be generated by each potential failure mode is related to the persistence of the discontinuities within the rock mass and the height of the face. If cropper joints were sufficiently persistent, then the entire slope would break-back to an angle of between 30-46° down single joints (a large planar failure). That this does not happen is due to the limited lateral extent of individual cropper joints. However, they do extend for 10 to 15m (and locally further for >50m) which means that this mode of failure has resulted in the local loss of bench crests. Such instability will generally be restricted to single bench scale failures. Bedding, although persistent as a textural feature, seldom forms a discrete discontinuity of wide extent.

Larger wedge failures may occur where cropper joints (and bedding surfaces) intersect with the perpendicular, sub-vertical joints. However, these are likely to be less extensive than potential planar break-back.

The potential for bench and large scale toppling instability is high, particularly where in close proximity to cleavage parallel faults which allow multi-bench instability. Pervasive cleavage allows for the development of instability at any level.

3.2.2 Purple Domain

The analysis detailed below relates to the general domain direction only *i.e.* for faces oriented towards 040°.

Instability mode	Potential	Notes
Planar	Localised break-back on scatter about C2 oriented joints where developed.	Majority of break-back on C2 joints eliminated with slopes flatter than 80°.
Wedge	Risk of wedge failure on intersections between croppers with joints C1/2/3 which will break-back beyond planar failures noted above.	Bench width should allow for a break-back of 4-5m behind assumed 75° design face angle.
Toppling	Minimal risk.	Minimal risk for general SW face orientation.

The greatest break-back potential arises from wedge type failures; this needs to be accommodated in bench design to ensure sufficient width for one way dumper access and edge protection.

3.2.3 Red and Blues Domain

The analysis detailed below relates to the general domain direction only *i.e.* for faces oriented towards 140°.

Instability mode	Potential	Notes
Planar	The majority of faces will break-back to 70-80° parallel to cleavage. Where bedding is present as a discontinuity (as opposed to a textural trace in slates) *i.e.* at a material boundary change (*e.g.* sandstone/clay beds) then there is potential for localised break-back to 50°.	Face angle of 75° should be adopted but the potential for larger localised break-back on bedding needs to be assessed as each bench is widened.
Wedge	Risk of wedge failure which will break-back beyond planar failures noted above.	Bench width should allow for a break-back of 5m behind assumed 75° design face angle.
Toppling	Limited localised potential for toppling.	Localised scaling of faces required particularly adjacent to dykes and faults.

The greatest break-back potential arises from planar break-back on relatively flatly dipping bedding surfaces. These are marked by material change *i.e.* from slate to sandstone. Within the slate proper the bedding does not often comprise a discontinuity surface and as such movements do not occur along them; where bedding does comprise a distinct discontinuity surface then break-back is likely.

3.3 <u>Excavated rock slope design arising from analysis</u>

The slope design described here relates primarily to the general final face alignment in each of the domains. The width of any bench must be sufficient to accommodate likely break-back calculated from the kinematic analysis and to allow for continued access and/or edge protection. Minimum bench widths relate to the size of mechanical plant used in the quarry and current HSE best practice guidance.

As noted above, in general the majority of planar and wedge instabilities on the steeper joints and cleavage would be eliminated by forming the excavated face to 75°. Localised break-back is likely to occur on the scatter about these joints and more specifically on the flatter cropper and bedding surfaces. The magnitude of this break-back depends on the structures present in each geotechnical domain.

For the **Hard Grey Domain** there is always the potential for break-back on cropper joints on the final southeastern faces. Observation of typical discontinuity trace length suggests that break-back of 5.5m behind the 75° face needs to be accommodated in the overall slope design. As such bench widths of 18.5m are required for 15m high faces where access needs to be maintained along their lengths. These bench widths accommodate potential wedge failures arising from intersections between cropper joints and all other discontinuities sets at the average orientations noted above. As such the overall slope will be *c.* 33° (1v:1.5h). There remains a continual possibility of toppling failure due to the cleavage and cropper joint intersection. The proposed bench widths will accommodate cleavage related toppling instability. In the lower south eastern faces where access is not required in the long term these benches may be reduced to 10.5m width subject to continued geotechnical inspection of discontinuity position slope and analysis of overall slope security.

For the **Purple Domain** the potential for planar break-back is largely eliminated by adopting a general face angle of 75°. There is a risk of additional break-back arising from localised wedge instability. This can be largely eliminated by adopting a general face angle flatter than 52°. Assuming an average break-back to half face height then an additional 4m bench width is needed for a 15m high face. Ideally the advancing bench widths should therefore be 14.5m wide for a 15m high face. As such the overall slope will be *c.* 38° (0.78v:1h).

For the **Red and Blues Domain** the potential for both planar and wedge type break-back is again largely eliminated by adopting a general face angle of 75°. However, there remains the risk of localised planar break-back along bedding surfaces. Minimum bench widths of 10.5m would be possible if bespoke barriers are used for edge protection, however where normal edge protection bunds are used, then 14.5m width benches are recommended. As such the recommended overall slope in the realignment area will be a maximum of *c.* 38° (0.78v:1h).

3.4 Long term slope design for the Boulder Clay slopes

Current excavations have shown that short term slopes (between 1 to 4 years) in the Boulder Clay overburden can be dug at *c.* 50-70°, but slope security in the longer term must consider the consequences of water pressures and long term *in situ* shear strength. The nature of these materials (clayey gravels) is such that gaining undisturbed samples for strength testing is impossible. Shear strength parameters for stability analysis have been derived from testing on recompacted samples using heavy compaction standards in a large shear box apparatus.

Given the thickness variations of the Boulder Clay, the design of the long term stable slopes has been undertaken for a number of different slope heights (10m, 20m and 30m) and for a number of potential water table conditions (modelled using a pore pressure ratio (r_u) approach). In such materials the r_u value is not likely to exceed 0.3; the Factor of Safety (FoS) stated below correspond to an r_u of 0.3 or above. The acceptable FoS for a long term slope is greater than 1.30.

The results of a series of limit equilibrium analyses for an *un-benched* Boulder Clay slope are set out in Appendix No. 2 and summarised below. The proposed slopes are conservative in that introducing intermediate benching improves the overall Factors of Safety, *i.e.* the overall security, of the slope. The following batters are included in all final excavation designs:

- Slopes up to 10m in height: single batter of 1v:1h (for which FoS = 1.42).
- Slopes up to 20m in height: individual face batters of 1v:1h but to include an intermediate bench 10m wide resulting in an overall slope of 1v:1.5h (for which the FoS = 1.30).
- Slopes in excess of 30m in height: individual face batters of 1v:1h but to include an intermediate bench 15m wide every 10m in height. This results in an overall slope of 1v:2h (for which the FoS = 1.62).

4. SUMMARY

The proposed realignment extension removes the step in the currently consented northwestern excavation limit. This results in improvements to overall slope security and health and safety.

The excavated slope design criteria have been derived from detailed geotechnical analysis. This is based on a regular programme of detailed geological and geotechnical field mapping to collect relevant discontinuity orientation data from each of the geotechnical domains recognised on site. The slope design criteria are reviewed in line with statutory requirement, at a minimum interval of 2 years, to comply with Regulation 30 of the Quarries Regulations. Where the geological structure or materials types varies from that assumed then additional analysis is undertaken to determine if any changes to the slope design are required.

The derived design criteria have been applied to the final excavation design within the realignment extension area from which quantities of recoverable materials have been determined.

GWP CONSULTANTS
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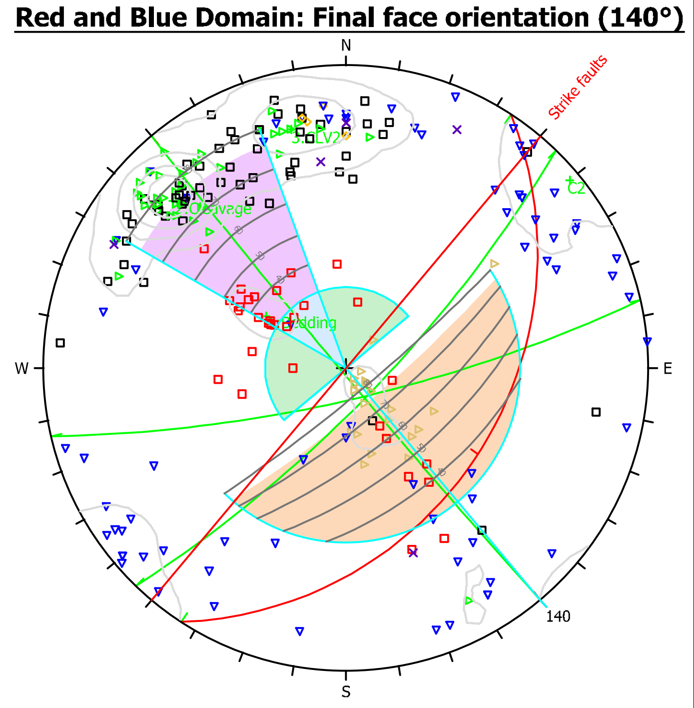
Table No. 1 - Summary of discontinuity orientations within the principal geotechnical domains

Set ID	Type	Average orientation (°) Hard Greys Domain (SE faces) Dip (°)	Average orientation (°) Hard Greys Domain (SE faces) Dip Dir. (°)	Notes
1	Bedding (variable and ranges between)	26 – 70	318 (NNW)	Usually apparent as greenish-grey traces within the purple grey slate but also locally present as a discontinuity surfaces. Bedding dips mostly to the NW.
2	Cleavage	78	131 (ESE)	Cleavage dips into the SE faces.
3	Joint (toe/foot joints)	12	320 (NNW)	Range in dip from sub-horizontal to 22°
4	Joint (cropper joints)	Average: 36 Range: 27-46	328 (NNW)	Consistent in orientation with shears
5	Joint C1	81	205	Cross joints approximately perpendicular to the above sets.
6		87	232	
7	Joint C3	N/A	N/A	

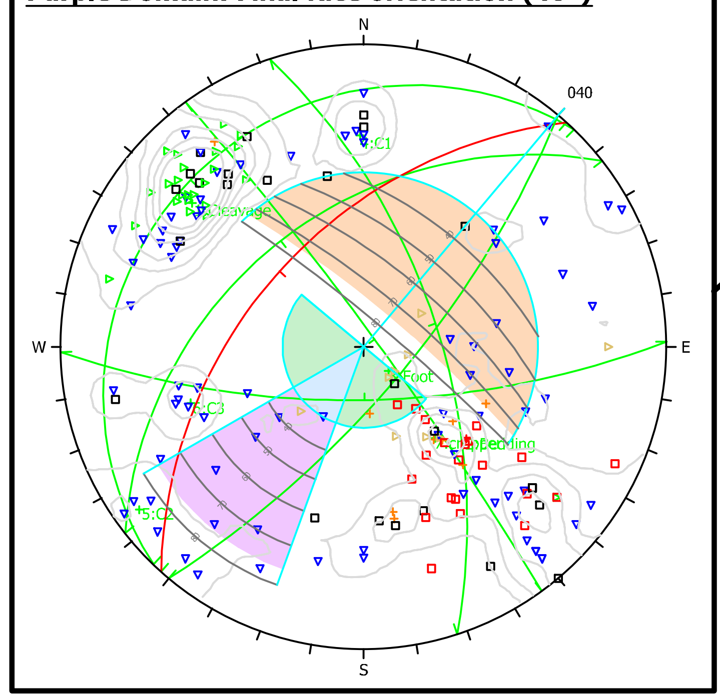
Set ID	Type	Average orientation (°) Purple Domain Dip (°)	Average orientation (°) Purple Domain Dip Dir. (°)	Notes
1	Bedding (variable and ranges between)	59	327 (NNW)	Towards the NW consistent with the Hard Greys Domain
2	Cleavage	76	132	Main cleavage direction same as Hard Greys Domain
3	Joint (toe/foot joints)	16	314	Range in dip up to 41° (i.e. cropper joints)
4	Joint (cropper joints)	Average: 42 Range: 27-56	322 (NNW)	Consistent in orientation with bedding
5	Joint C1	N/A	N/A	Not obvious in this area
6		85	54	Joints dips either side of vertical
7	Joint C3	62	72	Flatter joint causing potential wedges

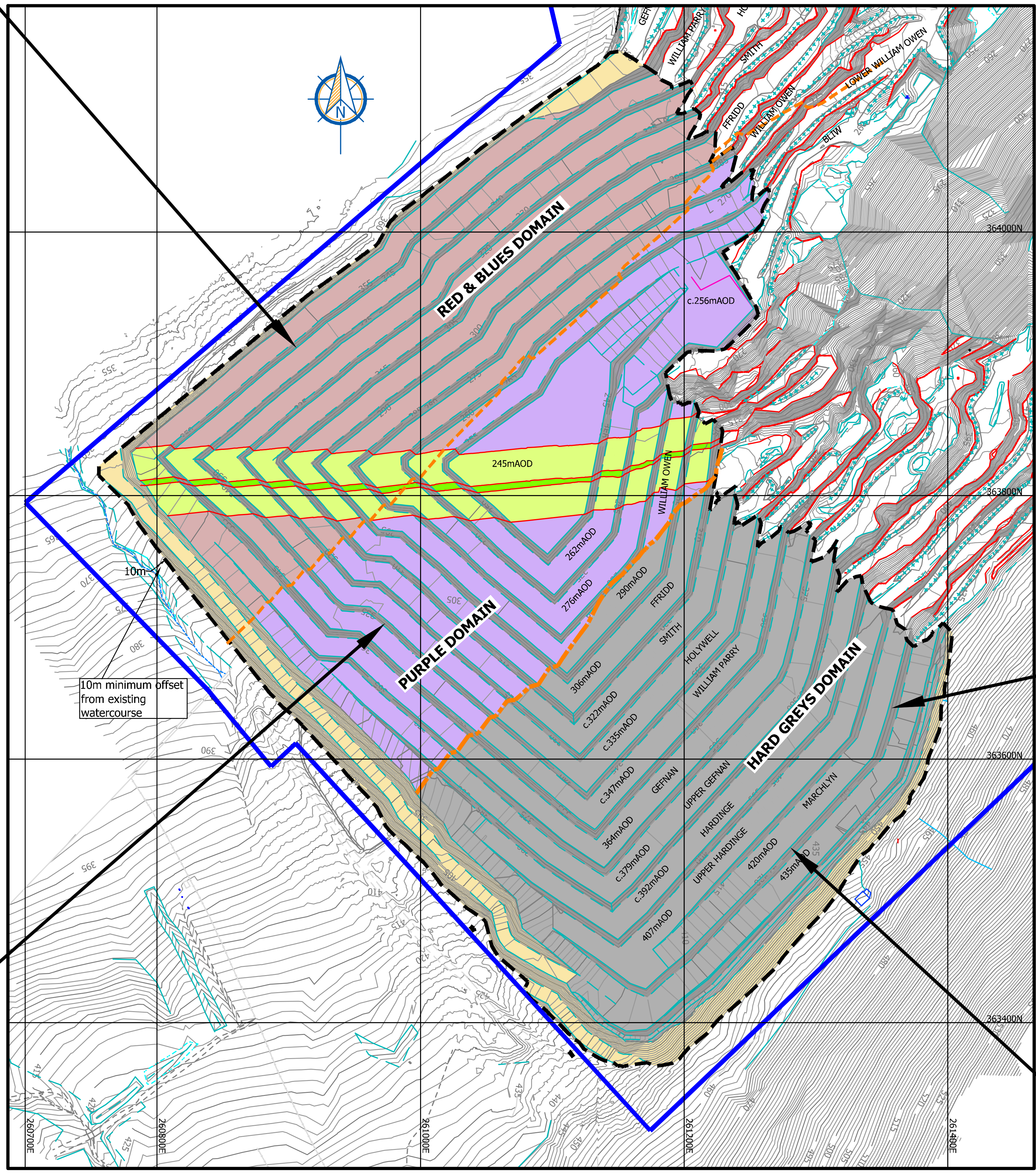
Set ID	Type	Average orientation (°) Red and Blues Domain Dip (°)	Average orientation (°) Red and Blues Domain Dip Dir. (°)	Notes
1	Bedding (variable and ranges between)	34	120 (SE)	Bedding dips predominantly to SE , but in some areas dips in opposite direction
2	Cleavage	76 78	135 170	Main cleavage direction same as Hard Greys Secondary set parallel to shears more towards the south
3	Joint (toe/foot joints)	8	314	Range in dip up to 33° (i.e. cropper joints)
4	Joint (cropper joints)	34 range 34-60	330	Not as prevalent as seen in Hard Greys Domain
5	Joint C1	89	47	Joints dips either side of vertical
6		75	232	Slightly shallower dip than in Hard Greys Domain
7	Joint C3	N/A	N/A	

Red and Blue Domain: Final face orientation (140°)

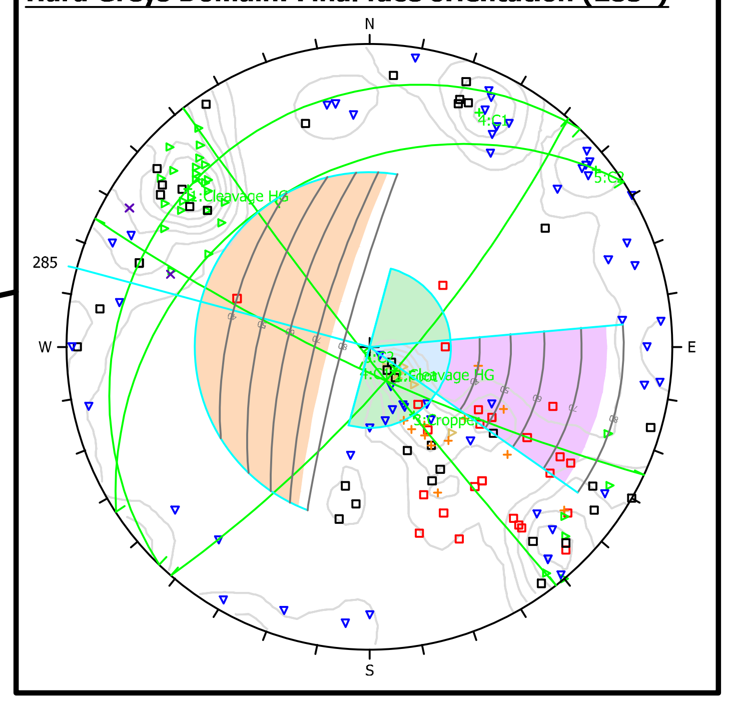


Purple Domain: Final face orientation (40°)

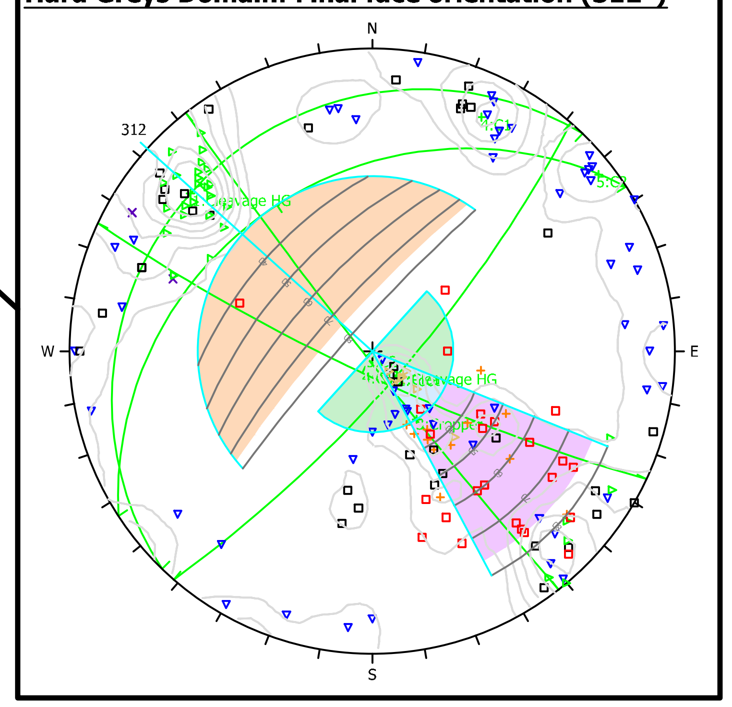




Hard Greys Domain: Final face orientation (285°)



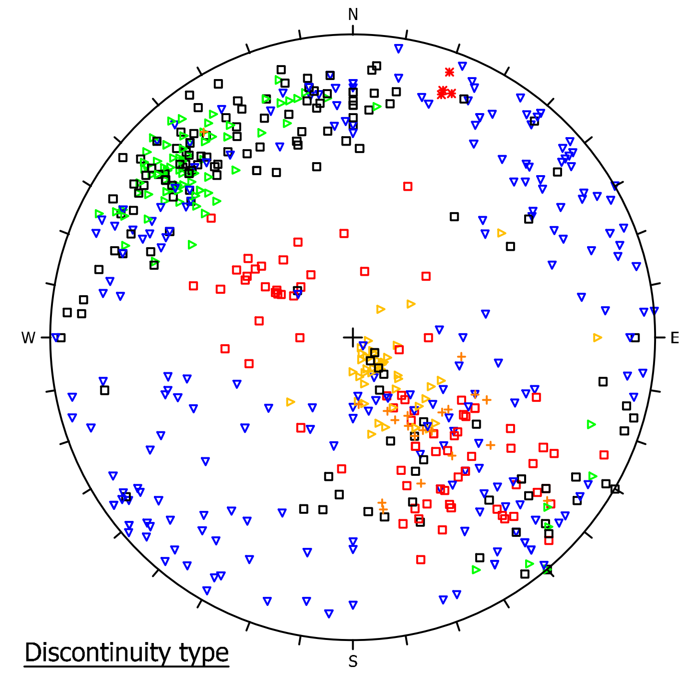
Hard Greys Domain: Final face orientation (312°)



PLAN LEGEND

- Company Land Holding
- Crest / Toe of quarry face
- Crest / Toe of slope
- Ground surface contours (mAOD)
- Excavated slopes in Boulder Clay
- Slate within the Hard Greys Domain
- Slate within the Purple Domain
- Slate within the Red and Blues Domain
- Dyke (extrapolated from outcrop) 25m envelope around dyke (waste)
- Conjectural position of Hard Grey Boundary Fault
- Conjectural position of Purple Boundary Fault

Stereographic projection of all discontinuity data - subdivided by discontinuity type only



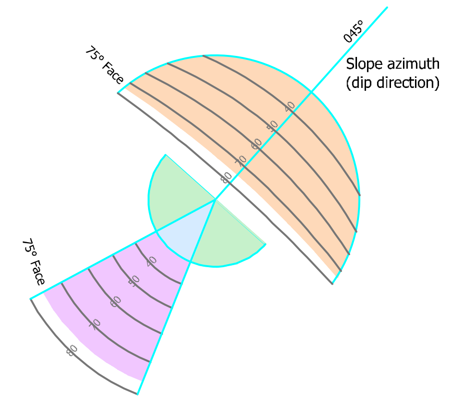
Discontinuity type

- Bedding [83]
- Cropper [21]
- Joint [216]
- Cleavage [98]
- Foot [45]
- Pillar [4]
- Others [154]

Average plane orientations

- Joints
- Bedding

KINEMATIC STABILITY OVERLAY



SHADING LEGEND FOR KINEMATIC STABILITY ASSESSMENT

Potential failure modes

- Planar, with some toppling, all poles falling in this region
- Wedge failures - intersections falling in these regions
- Large toppling failures, poles and intersections falling in this region
- Smaller, cross slope toppling failures, intersections falling in this region

Version	Revision and compilation notes	Date
A	Issued with report	08.11.2019
B	Final issued with report	12.11.2020

Client
Welsh Slate Ltd.

Project
Penrhyn Quarry - Geotechnical Considerations

Kinematic analysis for excavated rock slope design to the proposed realignment extension limit

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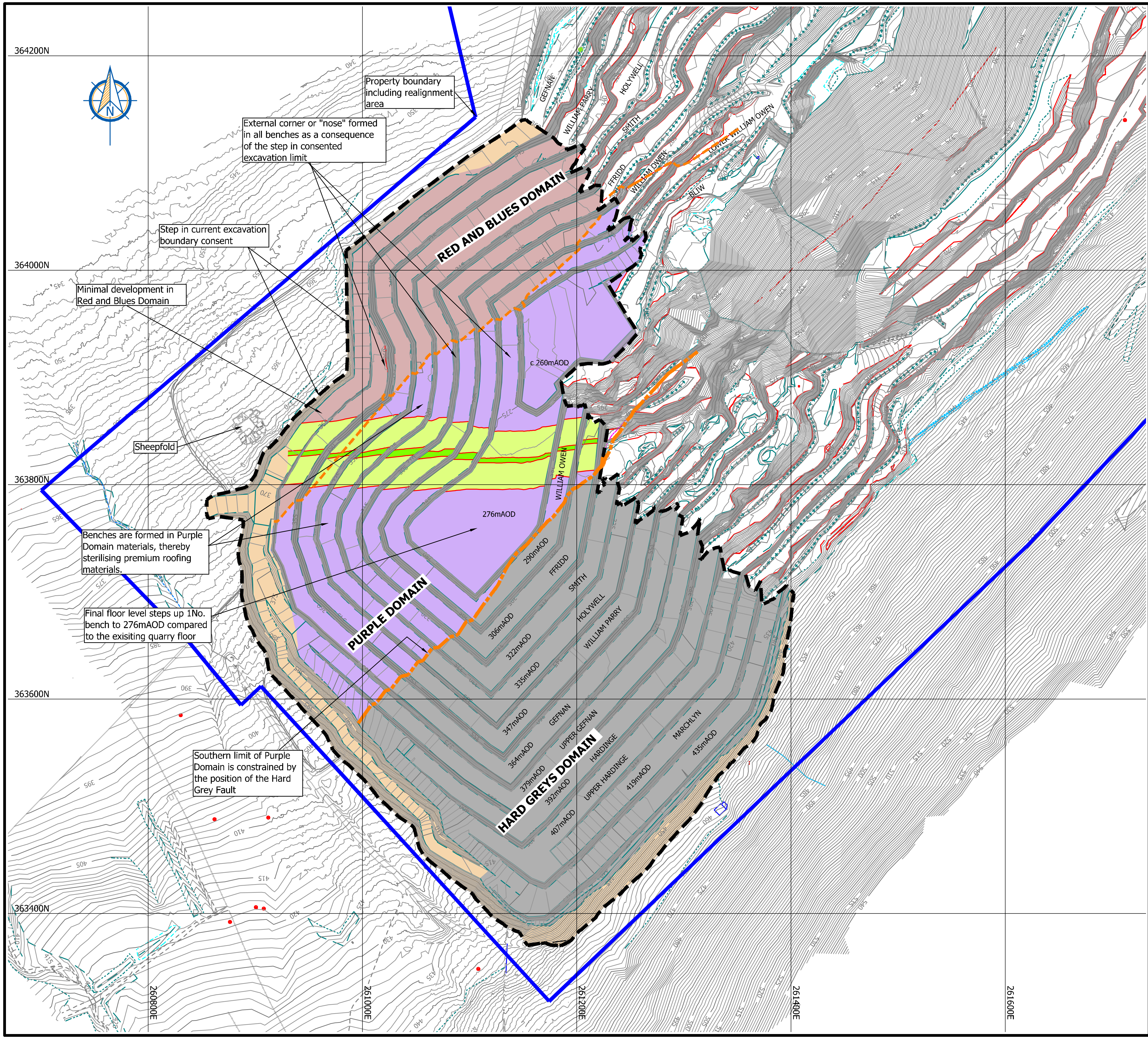
GWP Consultants LLP. Registered No. OC326183.
Registered Office: Upton House, Market Street, Charlbury, Oxfordshire OX7 3PJ, UK

Date	Drawn	Checked	Scale
12.11.2020	DJ/EMB	AEC	1:3000 at A2

Drawing Ref	Drawing No	Version
19WPENP1910GC	1	B



LEGEND

- Company Land Holding
- Crest / Toe of existing quarry face
- Crest / Toe of slope
- Ground surface contours (mAOD)
- Current consented limit of excavation

Inferred extent of slate domains in final excavation slopes

- Excavated slopes in superficials
- Hard Greys Domain
- Purple Domain
- Red and Blues Domain
- Dyke including 25m wide waste envelope (extrapolated from outcrop)
- Inferred extrapolated position of Hard Grey Fault
- Inferred extrapolated position of Purple Boundary Fault

Version	Revision and compilation notes	Date
A	Issued with report	08.11.2019
B	Final issued with report	12.11.2020

Client
Welsh Slate Limited

Project
Penrhyn Quarry - Geotechnical Considerations

Maximum excavation to the currently consented excavation limit

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Date	Drawn	Checked	Scale
12.11.2020	IB/EMB	AEC	1:3000 at A3

Drawing Ref	Drawing No	Version
19WPENP1910GC	2	B

APPENDIX 1

Discontinuity data

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
78	308	Bedding	Upper Gefnan	Purple	20mm thick buckled
85	295	Bedding	Upper Gefnan	Purple	
64	78	Joint	Upper Gefnan	Purple	
70	0	Joint	Upper Gefnan	Purple	Gives rise to chop
70	128	Joint	Upper Gefnan	Purple	
70	120	Fault	Upper Gefnan	Purple	
70	30	Joint	Upper Gefnan	Purple	
70	118	Joint	Upper Gefnan	Purple	
61	326	Joint	Upper Gefnan	Purple	
85	120	Fault	Upper Gefnan	Hard Greys	c15m throw across
62	300	Bedding	Upper Gefnan	Hard Greys	
90	300	Cleavage	Upper Gefnan	Hard Greys	
85	18	Joint	Upper Gefnan	Hard Greys	
89	320	Joint	Upper Gefnan	Hard Greys	
70	110	Fault	Upper Gefnan	Hard Greys	Cuts off an anticl
50	300	Bedding	Hardinge	Hard Greys	flex in bedding di
89	90	Joint	Hardinge	Hard Greys	
85	315	Cleavage	Hardinge	Hard Greys	
10	305	Foot Joint	Hardinge	Hard Greys	
81	315	Joint	Hardinge	Hard Greys	
85	232	Joint	Hardinge	Hard Greys	
50	300	Bedding	Hardinge	Hard Greys	
65	305	Bedding	Upper Hardinge	Purple	
65	150	Fault	William Parry	Purple	fault 1 at NW side
75	180	Fault	William Parry	Purple	fault 2 at NW side
75	135	Fault	William Parry	Purple	fault 3 at NW side
80	144	cropper	William Parry	Purple	
85	115	Joint	William Parry	Purple	
85	48	Joint	William Parry	Purple	
85	56	Joint	William Parry	Purple	
85	40	Joint	William Parry	Purple	
70	120	Joint	William Parry	Purple	
25	355	cropper	William Parry	Purple	local increases in
58	350	cropper	William Parry	Purple	local increases in
54	320	cropper	William Parry	Purple	local increases in
42	310	cropper	Hollywell	Purple	
85	305	Joint	Hollywell	Purple	
44	120	Bedding	Smith	Red & Blues	
88	202	Joint	Smith	Red & Blues	
78	130	Cleavage	Smith	Red & Blues	
22	355	Joint	Smith	Red & Blues	
44	320	cropper	Smith	Purple	
70	115	Joint	Smith	Purple	
70	175	Joint	Smith	Purple	
40	50	Joint	Smith	Purple	
50	314	Bedding	Ffridd	Purple	
82	105	Cleavage	Ffridd	Purple	
40	285	Joint	Ffridd	Purple	
88	242	Joint	Ffridd	Purple	
60	350	cropper	Ffridd	Purple	
49	305	Bedding	Ffridd	Purple	
75	130	Joint	Ffridd	Purple	
78	115	Fault	Ffridd	Red & Blues	Faces in floor

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
72	113	Fault	Ffridd	Red & Blues	Faces in floor
75	135	Shear	Ffridd	Red & Blues	
78	138	Fault	Ffridd	Red & Blues	
75	115	Joint	Ffridd	Red & Blues	
80	164	Joint	Ffridd	Red & Blues	
22	333	Foot Joint	Ffridd	Red & Blues	
38	138	Bedding	Ffridd	Red & Blues	
38	310	Joint	William Parry	Purple	
75	260	Joint	William Parry	Purple	
80	180	Joint	William Parry	Red & Blues	
80	170	Joint	William Parry	Red & Blues	
26	128	Joint	William Parry	Red & Blues	
72	12	Joint	Lower William Owen	Purple	
74	117	Joint	Lower William Owen	Purple	
48	295	cropper	Lower William Owen	Purple	
76	100	Joint	Lower William Owen	Purple	
50	312	Bedding	Lower William Owen	Purple	
42	323	cropper	William Owen	Purple	
74	140	Joint	William Owen	Purple	
60	228	Joint	William Owen	Purple	
72	132	Joint	William Owen	Purple	
48	301	Joint	William Owen	Purple	
42	320	Joint	William Owen	Purple	
78	308	Cleavage	William Owen	Purple	
78	25	Joint	William Owen	Purple	
45	68	Joint	William Owen	Purple	
48	305	Bedding	Hardinge	Hard Greys	
80	138	cleavage	Hardinge	Hard Greys	
78	38	Joint	Hardinge	Hard Greys	
65	288	Bedding	Hardinge	Hard Greys	
60	320	Bedding	Hardinge	Hard Greys	
28	270	Bedding	Hardinge	Hard Greys	
28	320	Bedding	Hardinge	Hard Greys	
44	320	Cropper	Hardinge	Hard Greys	
76	315	Joint	Hardinge	Hard Greys	
40	280	Cropper	Hardinge	Hard Greys	
90	240	Joint	Hardinge	Hard Greys	
38	328	Cropper	Hardinge	Hard Greys	
48	295	Joint	Hardinge	Hard Greys	
30	335	Cropper	Hardinge	Hard Greys	
83	0	Joint	Hardinge	Hard Greys	
85	302	Joint	Hardinge	Hard Greys	
80	310	Cropper	Hardinge	Hard Greys	
15	320	Toe joint	Hardinge	Hard Greys	
90	320	cleavage	Hardinge	Hard Greys	
42	328	Cropper	Hardinge	Hard Greys	
34	333	Cropper	Hardinge	Hard Greys	
80	264	Joint	Hardinge	Hard Greys	
84	314	cleavage	Hardinge	Hard Greys	
78	210	Joint	Hardinge	Hard Greys	
60	308	Cropper	Hardinge	Hard Greys	
11	323	Toe joint	Hardinge	Hard Greys	
43	307	Cropper	Upper Gefnan	Hard Greys	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
70	335	Bedding	Upper Gefnan	Hard Greys	
87	78	Joint	Upper Gefnan	Hard Greys	
56	335	Cropper	Upper Gefnan	Hard Greys	
82	140	cleavage	Upper Gefnan	Hard Greys	
86	316	Bedding	Upper Gefnan	Hard Greys	
40	10	Joint	Upper Gefnan	Hard Greys	
73	320	Bedding	Upper Gefnan	Hard Greys	
26	330	Joint	Upper Gefnan	Hard Greys	
49	313	Joint	Upper Gefnan	Hard Greys	
70	111	cleavage	Upper Gefnan	Hard Greys	
52	295	Cropper	Gefnan	Hard Greys	
80	210	Joint	Gefnan	Hard Greys	
60	323	Bedding	Gefnan	Hard Greys	
81	311	cleavage	Gefnan	Hard Greys	
88	189	Joint	Hollywell (n)	Hard Greys	
80	100	Joint	Hollywell (n)	Hard Greys	
85	5	Joint	Hollywell (n)	Hard Greys	
35	325	Cropper	Smith (n)	Hard Greys	
82	212	Joint	U Gefnan	Hard Greys	
86	230	Joint	U Gefnan	Hard Greys	
82	115	Joint	U Gefnan	Hard Greys	
30	315	Joint	U Gefnan	Hard Greys	
88	228	Joint	U Gefnan	Hard Greys	
86	205	Joint	U Gefnan	Hard Greys	
28	348	Joint	U Gefnan	Hard Greys	
74	212	Joint	U Gefnan	Hard Greys	
79	125	cleavage	U Gefnan	Hard Greys	
73	134	cleavage	U Gefnan	Hard Greys	
65	345	Bedding	U Gefnan	Hard Greys	
72	300	Bedding	U Gefnan	Hard Greys	
88	90	shear	U Gefnan	Hard Greys	
74	128	shear	U Gefnan	Hard Greys	
52	335	shear	U Gefnan	Hard Greys	
78	130	shear	U Gefnan	Hard Greys	
82	128	shear	U Gefnan	Hard Greys	
43	316	foot	Gefnan	Hard Greys	
82	200	pillar	Gefnan	Hard Greys	
81	200	pillar	Gefnan	Hard Greys	
86	200	pillar	Gefnan	Hard Greys	
82	202	pillar	Gefnan	Hard Greys	
86	135	cleavage	Gefnan	Hard Greys	
72	305	Bedding	Gefnan	Hard Greys	
81	310	Bedding	Gefnan	Hard Greys	
37	325	Bedding	Gefnan	Hard Greys	
84	98	tension	Gefnan	Hard Greys	
85	130	shear	Gefnan	Hard Greys	
78	110	shear	Gefnan	Hard Greys	
84	185	shear	Gefnan	Hard Greys	
42	328	shear	Gefnan	Hard Greys	
82	302	shear	Gefnan	Hard Greys	
53	305	shear	Gefnan	Hard Greys	
83	10	Joint	Wm Parry 1	Red & Blues	
82	190	Joint	Wm Parry 1	Red & Blues	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
43	125	Bedding	Wm Parry 1	Red & Blues	
37	120	Bedding	Wm Parry 1	Red & Blues	
70	134	cleavage	Wm Parry 1	Red & Blues	
80	160	shear	Wm Parry 1	Red & Blues	
75	136	shear	Wm Parry 1	Red & Blues	
62	235	foot	Wm Parry 1	Red & Blues	
78	225	Joint	Holywell 2	Red & Blues	
30	330	foot	Holywell 2	Red & Blues	
82	175	Joint	Holywell 2	Red & Blues	
25	320	foot	Holywell 2	Red & Blues	
85	135	reds fault	Holywell 2	Red & Blues	
80	160	dyke	Holywell 2	Red & Blues	
38	175	Bedding	Holywell 2	Red & Blues	
42	128	Bedding	Holywell 2	Red & Blues	
27	125	Bedding	Holywell 2	Red & Blues	
28	146	Bedding	Holywell 2	Red & Blues	
78	185	shear	Holywell 2	Red & Blues	
62	155	shear	Holywell 2	Red & Blues	
70	154	shear	Holywell 2	Red & Blues	
85	165	shear	Holywell 2	Red & Blues	
82	165	shear	Holywell 2	Red & Blues	
80	170	reds fault	Holywell 2	Red & Blues	
84	230	Joint	Smith 2	Red & Blues	
24	355	foot	Smith 2	Red & Blues	
84	130	cleavage	Smith 2	Red & Blues	
76	158	shear	Smith 2	Red & Blues	
80	110	shear	Smith 2	Red & Blues	
76	130	shear	Smith 2	Red & Blues	
72	132	shear	Smith 2	Red & Blues	
64	182	shear	Smith 2	Red & Blues	
80	280	shear	Smith 2	Red & Blues	
88	50	Joint	Smith 3	Red & Blues	
35	310	foot	Smith 3	Red & Blues	
40	150	Bedding	Smith 3	Red & Blues	
25	190	Bedding	Smith 3	Red & Blues	
80	150	shear	Smith 3	Red & Blues	
80	130	shear	Smith 3	Red & Blues	
80	170	shear	Smith 3	Red & Blues	
75	180	reds fault	Smith 3	Red & Blues	
88	55	Joint	Fridd 2	Red & Blues	
80	160	cleavage	Fridd 2	Red & Blues	
48	120	Bedding	Fridd 2	Red & Blues	
46	85	Bedding	Fridd 2	Red & Blues	
44	118	Bedding	Fridd 2	Red & Blues	
18	285	Bedding	Fridd 2	Red & Blues	
83	125	shear	Fridd 2	Red & Blues	
80	154	slick	Fridd 2	Red & Blues	
78	180	fault	Fridd 2	Red & Blues	
82	205	fault	Fridd 2	Red & Blues	
78	130	slick	Fridd 2	Red & Blues	
82	154	slick	Fridd 2	Red & Blues	
66	178	shear	Fridd 2	Red & Blues	
82	170	shear	Fridd 2	Red & Blues	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
78	174	dyke	Fridd 2	Red & Blues	
79	171	reds fault	Fridd 2	Red & Blues	
79	196	Joint	WM Owen 1	Red & Blues	
40	325	foot	WM Owen 1	Red & Blues	
78	138	cleavage	WM Owen 1	Red & Blues	
20	90	Bedding	WM Owen 1	Red & Blues	
76	180	shear	WM Owen 1	Red & Blues	
9	338	foot	WM Owen 2	Red & Blues	
82	55	Joint	WM Owen 2	Red & Blues	
82	130	shear	WM Owen 2	Red & Blues	
79	190	shear	WM Owen 2	Red & Blues	
82	175	reds fault	WM Owen 2	Red & Blues	
75	220	Joint	Lwr WM Owen	Red & Blues	
68	180	Joint	Hardinge	Purple	
80	80	Joint	Hardinge	Purple	
68	130	cleavage	Hardinge	Purple	
70	132	cleavage	Hardinge	Purple	
74	132	cleavage	Hardinge	Purple	
40	320	shear	Hardinge	Purple	
72	142	boundary fa	Hardinge	Purple	
43	320	foot	U Gefnan	Purple	
70	180	Joint	U Gefnan	Purple	
72	310	clay	U Gefnan	Purple	
76	312	clay	U Gefnan	Purple	
72	180	dyke	U Gefnan	Purple	
74	136	cleavage	U Gefnan	Purple	
78	143	cleavage	U Gefnan	Purple	
76	148	cleavage	U Gefnan	Purple	
68	145	cleavage	U Gefnan	Purple	
74	130	cleavage	U Gefnan	Purple	
62	350	clay	U Gefnan	Purple	
60	340	fault	U Gefnan	Purple	
18	320	shear	U Gefnan	Purple	
35	340	foot	Gefnan	Purple	
86	36	Joint	Gefnan	Purple	
75	40	Joint	Gefnan	Purple	
32	265	Joint	Gefnan	Purple	
72	312	Bedding	Gefnan	Purple	
40	325	foot	Gefnan	Purple	
82	148	cleavage	Gefnan	Purple	
80	130	cleavage	Gefnan	Purple	
78	150	cleavage	Gefnan	Purple	
76	128	cleavage	Gefnan	Purple	
60	355	clay	Gefnan	Purple	
68	0	Joint	WM Owen 3	Purple	
48	260	Joint	WM Owen 3	Purple	
58	232	Joint	WM Owen 3	Purple	
52	280	Joint	WM Owen 3	Purple	
86	240	Joint	WM Owen 3	Purple	
64	286	Joint	WM Owen 3	Purple	
68	159	Joint	WM Owen 3	Purple	
60	292	Joint	WM Owen 3	Purple	
80	140	wedge 1	WM Owen 3	Purple	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
72	310	wedge 2	WM Owen 3	Purple	
60	168	wedge 3	WM Owen 3	Purple	
68	320	Joint	WM Owen 3	Purple	
72	235	Joint	WM Owen 3	Purple	
71	312	Joint	WM Owen 3	Purple	
69	316	Joint	WM Owen 3	Purple	
71	178	Joint	WM Owen 3	Purple	
78	110	Joint	WM Owen 3	Purple	
78	135	shear	WM Owen 3	Purple	
80	78	shear	WM Owen 3	Purple	
80	330	shear	WM Owen 3	Purple	
35	320	Bedding	bb1	Purple	
50	340	Bedding	bb1	Purple	
85	320	Joint	bb1	Purple	
85	135	cleavage	bb1	Purple	
70	140	shear	bb1	Purple	
50	320	Joint	bb1	Purple	
45	320	Bedding	bb1	Purple	
30	320	Bedding	bb2	Purple	
25	330	Bedding	bb2	Purple	
85	320	Joint	bb2	Purple	
80	135	cleavage	bb2	Purple	
85	310	Joint	bb2	Purple	
85	135	cleavage	bb2	Purple	
88	256	Joint	F1	Red & Blues	
90	265	Joint	F1	Red & Blues	
88	74	Joint	F1	Red & Blues	
78	226	Joint	F1	Red & Blues	
84	29	Joint	F1	Red & Blues	
77	174	cleavage	F1	Red & Blues	
35	100	Bedding	F1	Red & Blues	
69	173	fault	F2	Red & Blues	
80	130	cleavage	F2	Red & Blues	
85	135	cleavage	F2	Red & Blues	
79	133	cleavage	F2	Red & Blues	
82	118	fault	F2	Red & Blues	
78	180	fault	F2	Red & Blues	
87	282	Joint	F2	Red & Blues	
9	303	foot	F2	Red & Blues	
7	330	foot	F2	Red & Blues	
78	167	cleavage	F2	Red & Blues	
39	76	Bedding	F2	Red & Blues	
75	136	shear	F2	Red & Blues	
66	340	fault	F2	Red & Blues	
82	126	cleavage	F3	Purple	
75	61	Joint	F3	Purple	
78	116	Joint	F3	Purple	
75	120	Joint	F3	Purple	
74	318	Joint	F3	Purple	
77	318	Bedding	F3	Purple	
78	112	cleavage	g1	Red & Blues	
75	140	cleavage	g2	Purple	
30	30	Joint	g3	Purple	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
50	50	Joint	g3	Purple	
83	320	Joint	g3	Purple	
85	140	Joint	g3	Purple	
61	16	shear	g3	Purple	
15	320	foot	g3	Purple	
58	315	Bedding	g3	Purple	
75	320	Bedding	ghg1	Hard Greys	
75	130	cleavage	ghg1	Hard Greys	
75	136	cleavage	ghg1	Hard Greys	
68	135	cleavage	ghg1	Hard Greys	
85	320	Joint	ghg1	Hard Greys	
25	330	Joint	ghg1	Hard Greys	
35	320	Joint	ghg1	Hard Greys	
15	310	foot	HD1	Hard Greys	
88	30	Joint	HD1	Hard Greys	
70	130	cleavage	HD1	Hard Greys	
62	336	Bedding	HD1	Hard Greys	
55	340	Bedding	HG1	Hard Greys	
88	265	Joint	HG1	Hard Greys	
85	206	Joint	HG1	Hard Greys	
85	248	Joint	HG1	Hard Greys	
80	210	Joint	HG1	Hard Greys	
85	142	cleavage	HG1	Hard Greys	
87	322	cleavage	HG1	Hard Greys	
80	250	Joint	HG2	Hard Greys	
78	170	Joint	HG2	Hard Greys	
87	230	Joint	HG2	Hard Greys	
78	172	Joint	HG2	Hard Greys	
85	278	Joint	HG2	Hard Greys	
88	277	Joint	HG2	Hard Greys	
15	300	foot	HG2	Hard Greys	
10	320	foot	HG2	Hard Greys	
85	112	Joint	HG2	Hard Greys	
75	130	cleavage	HG2	Hard Greys	
77	134	cleavage	HG2	Hard Greys	
78	135	cleavage	HG2	Hard Greys	
78	110	shear	HG2	Hard Greys	
70	130	shear	HG2	Hard Greys	
81	126	shear	HG2	Hard Greys	
85	306	shear	HG2	Hard Greys	
88	324	shear	HG2	Hard Greys	
88	146	shear	HG2	Hard Greys	
76	320	Bedding	HG3	Hard Greys	
17	332	Joint	HG3	Hard Greys	
76	120	cleavage	HG3	Hard Greys	
70	134	cleavage	HW1	Red & Blues	
81	45	Joint	HW1	Red & Blues	
86	251	Joint	HW1	Red & Blues	
71	236	Joint	HW1	Red & Blues	
70	35	Joint	HW1	Red & Blues	
78	34	Joint	HW1	Red & Blues	
73	226	Joint	HW1	Red & Blues	
6	282	foot	HW1	Red & Blues	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
47	127	Bedding	HW1	Red & Blues	
27	134	Bedding	HW2	Red & Blues	
75	135	cleavage	HW2	Red & Blues	
84	238	Joint	HW2	Red & Blues	
60	330	Joint	HW2	Red & Blues	
79	180	Joint	HW2	Red & Blues	
36	349	foot	HW2	Red & Blues	
72	141	shear	HW2	Red & Blues	
76	189	shear	HW2	Red & Blues	
75	141	shear	HW2	Red & Blues	
73	146	shear	HW2	Red & Blues	
80	140	cleavage	HW3	Red & Blues	
85	132	cleavage	HW3	Red & Blues	
64	22	Joint	HW3	Red & Blues	
83	328	Joint	HW3	Red & Blues	
71	324	Joint	HW3	Red & Blues	
85	312	Joint	HW3	Red & Blues	
81	326	Joint	HW3	Red & Blues	
85	54	Joint	HW3	Red & Blues	
71	63	Joint	HW3	Red & Blues	
83	328	Joint	HW3	Red & Blues	
85	47	Joint	HW3	Red & Blues	
15	225	foot	HW3	Red & Blues	
70	320	shear	HW3	Red & Blues	
79	131	cleavage	HW3	Red & Blues	
82	332	cleavage	HW3	Red & Blues	
45	320	Bedding	Iwo1	Red & Blues	
50	324	Bedding	Iwo1	Red & Blues	
85	135	Joint	Iwo1	Red & Blues	
25	350	foot	Iwo1	Red & Blues	
80	144	cleavage	Iwo1	Red & Blues	
75	136	shear	Iwo1	Red & Blues	
80	120	shear	Iwo1	Red & Blues	
75	171	shear	Iwo1	Red & Blues	
77	135	shear	Iwo1	Red & Blues	
87	152	shear	Iwo1	Red & Blues	
79	144	shear	Iwo1	Red & Blues	
79	138	shear	Iwo2	Red & Blues	
75	138	shear	Iwo2	Red & Blues	
77	136	shear	Iwo2	Red & Blues	
75	135	shear	Iwo2	Red & Blues	
5	320	foot	Iwo2	Red & Blues	
13	312	foot	Iwo2	Red & Blues	
78	198	Joint	Iwo2	Red & Blues	
77	232	Joint	Iwo2	Red & Blues	
48	330	Joint	Iwo2	Red & Blues	
25	330	Bedding	Iwo2	Red & Blues	
45	330	Bedding	Iwo2	Red & Blues	
52	320	Bedding	Iwo£	Purple	
72	146	Joint	Iwo3	Purple	
80	180	Joint	Iwo3	Purple	
79	132	cleavage	Iwo3	Purple	
78	130	shear	Iwo3	Purple	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
55	220	shear	lwo3	Purple	
45	330	Bedding	lwo4	Purple	
61	329	Bedding	lwo4	Purple	
83	320	Joint	lwo4	Purple	
40	270	Joint	lwo4	Purple	
15	308	foot	lwo4	Purple	
90	320	sub	lwo4	Purple	
83	136	cleavage	lwo4	Purple	
62	240	shear	NP1	North Pit	
56	200	Bedding	NPW1	North Pit	
77	310	Bedding	NPW1	North Pit	
47	5	Bedding	NPW1	North Pit	
34	302	foot	NPW1	North Pit	
13	360	foot	NPW1	North Pit	
86	228	Joint	NPW1	North Pit	
73	156	cleavage	NPW1	North Pit	
78	145	cleavage	NPW1	North Pit	
80	130	cleavage	NPW1	North Pit	
86	270	shear	NPW1	North Pit	
74	184	shear	NPW1	North Pit	
27	130	shear	NPW1	North Pit	
76	140	shear	NPW1	North Pit	
83	314	shear	NPW1	North Pit	
88	300	shear	NPW1	North Pit	
86	284	fold	NPW1	North Pit	
87	289	fold	NPW1	North Pit	
38	30	Bedding	NPW2	North Pit	
58	108	Bedding	NPW2	North Pit	
14	341	foot	NPW2	North Pit	
15	350	foot	NWP2	North Pit	
13	336	foot	NWP2	North Pit	
18	346	foot	NWP2	North Pit	
82	150	Joint	NWP2	North Pit	
87	46	Joint	NWP2	North Pit	
75	228	Joint	NWP2	North Pit	
85	30	Joint	NWP2	North Pit	
45	310	Joint	NWP2	North Pit	
38	300	Joint	NWP2	North Pit	
62	288	Joint	NWP2	North Pit	
86	116	cleavage	NWP2	North Pit	
83	118	cleavage	NWP2	North Pit	
81	124	cleavage	NWP2	North Pit	
84	95	shear	NWP2	North Pit	
88	128	shear	NWP2	North Pit	
85	55	shear	NWP2	North Pit	
81	137	shear	NWP2	North Pit	
82	231	shear	NWP2	North Pit	
76	172	sg	NWP2	North Pit	
83	140	fault	NWP2	North Pit	
85	146	fault	NPW2	North Pit	
83	239	Joint	SM1	Red & Blues	
85	71	Joint	SM1	Red & Blues	
35	316	foot	SM1	Red & Blues	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
83	136	cleavage	SM1	Red & Blues	
68	164	shear	SM1	Red & Blues	
75	186	cleavage	SM2	Red & Blues	
73	163	cleavage	SM2	Red & Blues	
78	163	cleavage	SM2	Red & Blues	
79	103	Joint	SM2	Red & Blues	
74	242	Joint	SM2	Red & Blues	
15	332	foot	SM2	Red & Blues	
78	136	cleavage	SM4	Red & Blues	
82	119	cleavage	SM5	Red & Blues	
85	341	Joint	SM5	Red & Blues	
82	119	Joint	SM5	Red & Blues	
85	338	Joint	SM5	Red & Blues	
88	40	Joint	SM5	Red & Blues	
78	130	shear	SM5	Red & Blues	
23	312	foot	SM5	Red & Blues	
73	330	Joint	SM5	Red & Blues	
78	230	Joint	UB1	Hard Greys	
16	318	foot	UB1	Hard Greys	
75	176	Joint	UB1	Hard Greys	
35	230	Bedding	UB1	Hard Greys	
50	110	Bedding	UB1	Hard Greys	
63	120	cleavage	UB1	Hard Greys	
82	132	cleavage	UB1	Hard Greys	
75	164	shear	UB1	Hard Greys	
63	130	Bedding	ug1	Red & Blues	
65	135	cleavage	ug1	Red & Blues	
65	130	cleavage	ug1	Hard Greys	
80	320	Joint	ug2	Purple	
25	240	foot	ug2	Purple	
70	250	Joint	ug2	Purple	
65	50	Joint	ug2	Purple	
75	135	cleavage	ug3	Hard Greys	
78	138	cleavage	ug3	Hard Greys	
75	126	cleavage	ug3	Hard Greys	
76	128	cleavage	ug3	Hard Greys	
80	50	Joint	ug3	Hard Greys	
25	340	Joint	ug3	Hard Greys	
30	0	Joint	ug3	Hard Greys	
50	10	shear	ug3	Hard Greys	
55	5	shear	ug3	Hard Greys	
60	10	shear	ug3	Hard Greys	
50	330	shear	ug3	Hard Greys	
40	340	shear	ug3	Hard Greys	
75	300	Bedding	ug3	Hard Greys	
45	300	Bedding	ug3	Hard Greys	
60	320	Bedding	UGG1	Hard Greys	
5	310	Joint	UGG1	Hard Greys	
80	290	cleavage	UGG1	Hard Greys	
85	300	cleavage	UGG1	Hard Greys	
85	253	Joint	UH2	Hard Greys	
85	230	Joint	UH2	Hard Greys	
85	270	Joint	UH2	Hard Greys	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
15	312	foot	UH2	Hard Greys	
82	206	Joint	UH2	Hard Greys	
14	326	foot	UH2	Hard Greys	
22	310	foot	UH2	Hard Greys	
79	136	cleavage	UH2	Hard Greys	
83	129	cleavage	UH2	Hard Greys	
88	286	shear	UH2	Hard Greys	
80	320	shear	UH2	Hard Greys	
70	236	shear	UH2	Hard Greys	
76	148	cleavage	US2	Red & Blues	
78	238	Joint	US2	Red & Blues	
36	296	foot	US2	Red & Blues	
75	137	Joint	wo2	Red & Blues	
33	343	foot	wo2	Red & Blues	
88	248	Joint	wo2	Red & Blues	
65	150	shear	wo2	Red & Blues	
70	180	shear	wo2	Red & Blues	
70	166	shear	wo2	Red & Blues	
71	138	cleavage	wo2	Red & Blues	
57	310	Joint	wo3	Red & Blues	
10	306	foot	wo3	Red & Blues	
83	184	shear	wo3	Red & Blues	
75	131	cleavage	wo3	Red & Blues	
81	129	cleavage	wo3	Red & Blues	
81	146	cleavage	wo3	Red & Blues	
30	330	Bedding	wo3	Red & Blues	
77	160	Joint	wo3	Red & Blues	
75	245	Joint	wo3	Red & Blues	
26	360	Joint	wo3	Red & Blues	
37	25	Joint	wo3	Red & Blues	
9	324	foot	wo3	Red & Blues	
65	340	Bedding	wo4	Red & Blues	
66	330	Bedding	wo4	Red & Blues	
75	150	shear	wo4	Red & Blues	
81	124	shear	wo4	Red & Blues	
87	95	shear	wo4	Red & Blues	
67	164	shear	wo4	Red & Blues	
79	131	shear	wo4	Red & Blues	
79	176	Joint	wo4	Red & Blues	
86	140	cleavage	wo4	Red & Blues	
83	164	cleavage	wo4	Red & Blues	
81	118	cleavage	wo5	Purple	
72	128	cleavage	wo5	Purple	
82	126	cleavage	wo5	Purple	
77	151	shear	wo5	Purple	
59	76	Joint	wo5	Purple	
65	74	Joint	wo5	Purple	
66	73	Joint	wo5	Purple	
63	71	Joint	wo5	Purple	
60	66	Joint	wo5	Purple	
60	330	Bedding	wo5	Purple	
65	330	Bedding	wo5	Purple	
80	140	Joint	wo5	Purple	

Appendix No. 1 - Discontinuity data

Dip	Azimuth	Type	Bench	Domian	Notes
75	124	Joint	wo5	Purple	
70	130	Joint	wo5	Purple	
60	320	Joint	wo5	Purple	
82	54	Joint	wo5	Purple	
89	49	Joint	WP1	Red & Blues	
86	218	Joint	WP1	Red & Blues	
62	316	Joint	WP1	Red & Blues	
74	132	cleavage	WP1	Red & Blues	
76	134	cleavage	WP1	Red & Blues	
88	50	Joint	WP2	Red & Blues	
85	220	Joint	WP2	Red & Blues	
32	120	Bedding	WP3	Red & Blues	
33	122	Bedding	WP3	Red & Blues	
85	60	Joint	WP3	Red & Blues	
88	215	Joint	WP3	Red & Blues	
78	130	cleavage	WP3	Red & Blues	
80	132	cleavage	WP3	Red & Blues	
33	120	Bedding	WP4	Red & Blues	
31	121	Bedding	WP4	Red & Blues	
86	55	Joint	WP4	Red & Blues	
88	220	Joint	WP4	Red & Blues	
83	130	cleavage	WP4	Red & Blues	
79	169	cleavage	WP4	Red & Blues	
78	165	cleavage	WP4	Red & Blues	
86	220	shear	WP4	Red & Blues	
70	150	shear	WP4	Red & Blues	
81	142	shear	WP4	Red & Blues	
77	169	shear	WP4	Red & Blues	
82	130	shear	WP4	Red & Blues	
62	340	Bedding	WP5	Purple	
75	343	Bedding	WP5	Purple	
17	280	foot	WP5	Purple	
33	44	foot	WP5	Purple	
75	131	cleavage	WP5	Purple	
78	270	foot	WP6	Purple	
87	220	Joint	WP6	Purple	
88	55	Joint	WP6	Purple	
76	130	cleavage	WP6	Purple	

APPENDIX 2

In situ Boulder Clay slope design – parametric study to establish stable long-term Boulder Clay slopes

Appendix 2 - *In situ* Boulder Clay slope design

Parametric study to establish stable long term Boulder Clay slopes

Boulder Clay strength parameters

Derived from shear box testing by Fugro Ltd (heavy compaction)

c' = 26 kPa

Ø' = 32.5 º

Density = 2.1 Mg/m³

Results of parametric study based on an *un-benched* slopes as defined below:

30m high slope

Overall Face Gradient	Factor of Safety			
	Dry	ru=0.1	ru=0.2	ru=0.3
1:1	1.22	1.08	0.95	0.82
1:1.5	1.57	1.42	1.27	1.12
1:2	1.94	1.76	1.59	*1.41

*15m wide benches at 10m vertical intervals

20m high slope

Overall Face Gradient	Factor of Safety			
	Dry	ru=0.1	ru=0.2	ru=0.3
1:1	1.39	1.25	1.12	0.98
1:1.5	1.77	1.62	1.46	**1.3
1:2	2.16	1.98	1.80	1.60

**10m wide benches at 10m vertical intervals

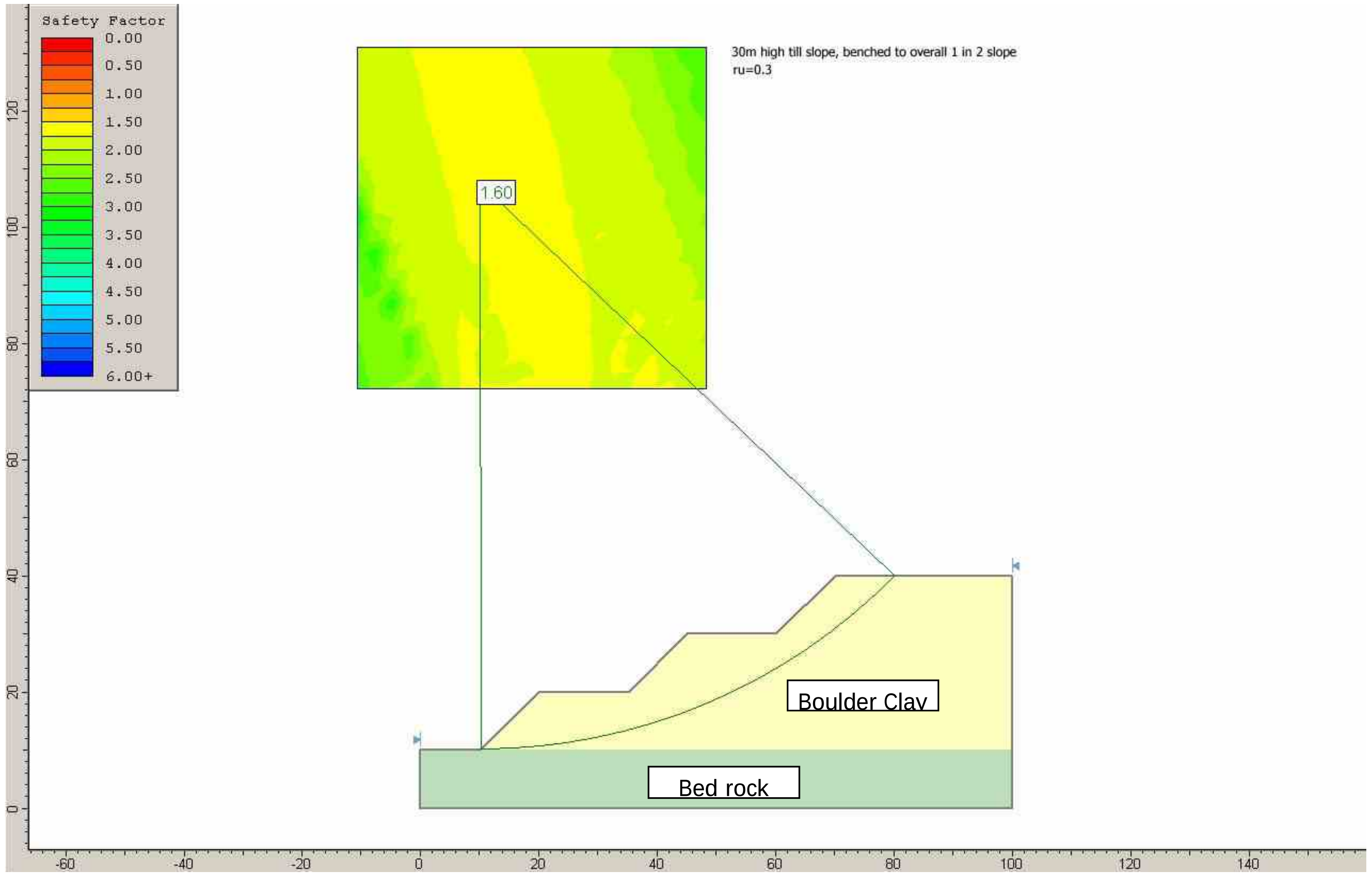
10m high slope

Face Gradient	Factor of Safety			
	Dry	ru=0.1	ru=0.2	ru=0.3
1:1	1.86	1.72	1.57	***1.42
1:1.5	2.32	2.15	1.99	1.82
1:2	2.77	2.58	2.39	2.20

*** Single batter

Note:

Assumes no weak units within Boulder Clay materials, should any be found then redesign may be necessary.



Example of typical analysis using conventional limit equilibrium techniques.

Note, increased FoS for benched slope compared to those of un-benched slopes in results tables (in above case by *c.* 12% *i.e.* from a single batter where FoS=1.41 to a benched batter where FoS=1.60)