Glasgow City Council

Linn Park, Glasgow

Rock Slope Geotechnical Assessment and Remedial Options Appraisal Report

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RSK GEOSCIENCES

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Revision reference	**Date**	**Reason for revision**
Rev 00	December 2021	First issue
Rev 01	January 2022	Updated with remedial option cost estimates

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CONTENTS

APPENDICES

1 INTRODUCTION

1.1 Commissioning

RSK Environment Limited (RSK) were commissioned by Glasgow City Council (GCC) to carry out a geotechnical inspection of a section of rock escarpment in Linn Park, near Cathcart, Glasgow.

Objective is agreed

Recent rockfalls from the rocky crags have resulted in closure of a footpath at its toe. The aim of the inspection is to determine best remedial options at the location of the recent rock fall and also prevent future rock fall in nearby vulnerable locations, if deemed necessary, with a view to re-opening the footpath to the public.

This report is subject to the RSK service constraints given in **Appendix A** and limitations that may be described within this document.

1.2 Objectives

The specific objectives of the geotechnical assessment and remedial/mitigation options appraisal are:

1. An assessment of rock slope condition at the location of the recent rock fall and adjacent areas, as identified by GCC, giving consideration to any indicators of more significant slope instability that could cause greater risk, if present.
2. The identification of any similarly unstable areas of rock slope, along the length of the path, which may also require remediation.
3. An appraisal of remedial options at the location of the most recent rock fall and similarly unstable areas along the path, as deemed necessary, with consideration to technical suitability, cost-effectiveness and long-term viability (including maintenance implications).
4. An assessment of the likely costs of remedial options and approximate timescales.

1.3 Limitations

In summary
A wander down the path, a few photos, and a desk study of published data

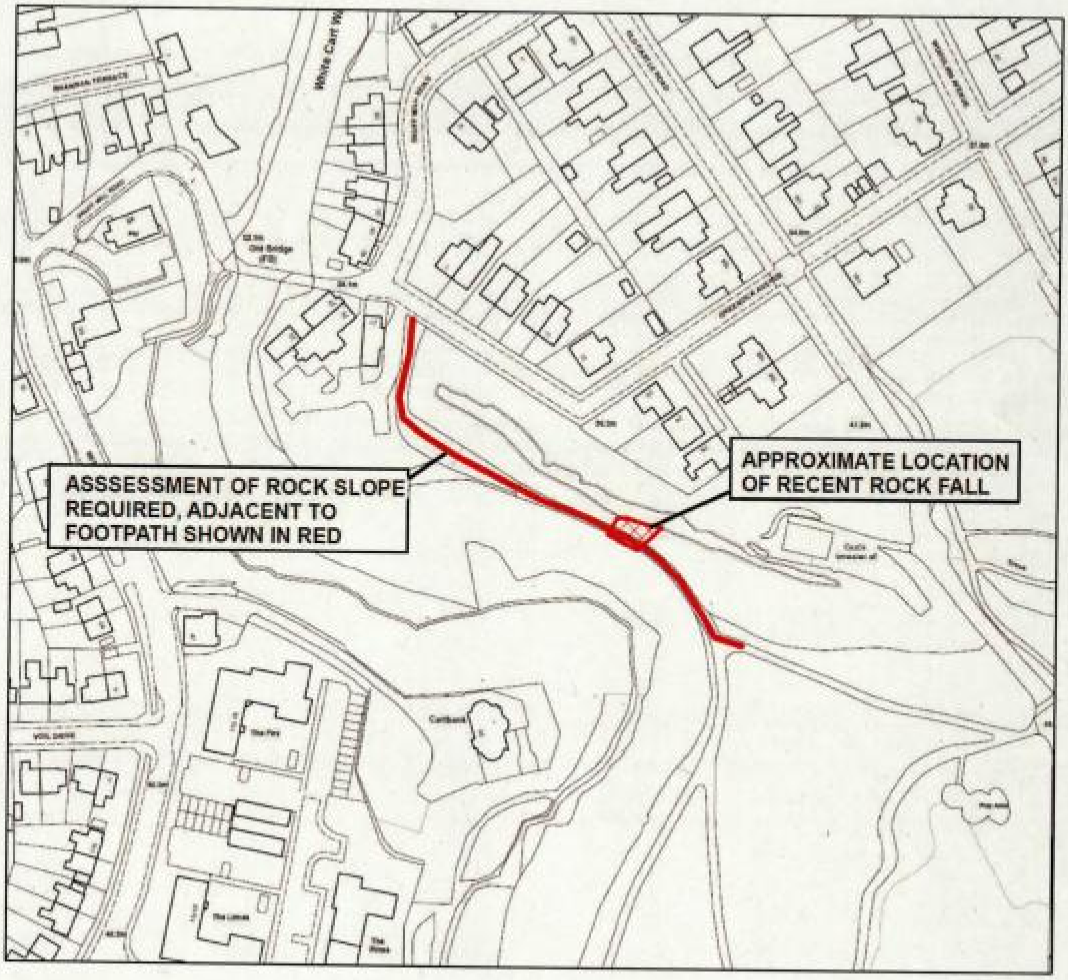
The comments given in this report and the opinions expressed are based on a visual inspection and descriptions and measurements of prominent features (rock material, discontinuities, vegetation etc.) but has not included any destructive or intrusive investigation (boreholes or geotechnical testing) or specialist arboriculture advice.

No site specific topographical survey data is available at the time of writing and RSK have used publicly available Third Party data. RSK cannot be held responsible for any errors or omissions within Third Party data and recommend that topographic constraints are checked and addressed at detailed design stage.

2 SITE DETAILS

The site is located in the northern part of Linn Park, near Cathcart, Glasgow and comprises a 180 m long section of craggy rock escarpment on the eastern bank of the White Cart Water river. The section is centred at National Grid Reference 258640, 660070.

Figure 1: Site Location Plan



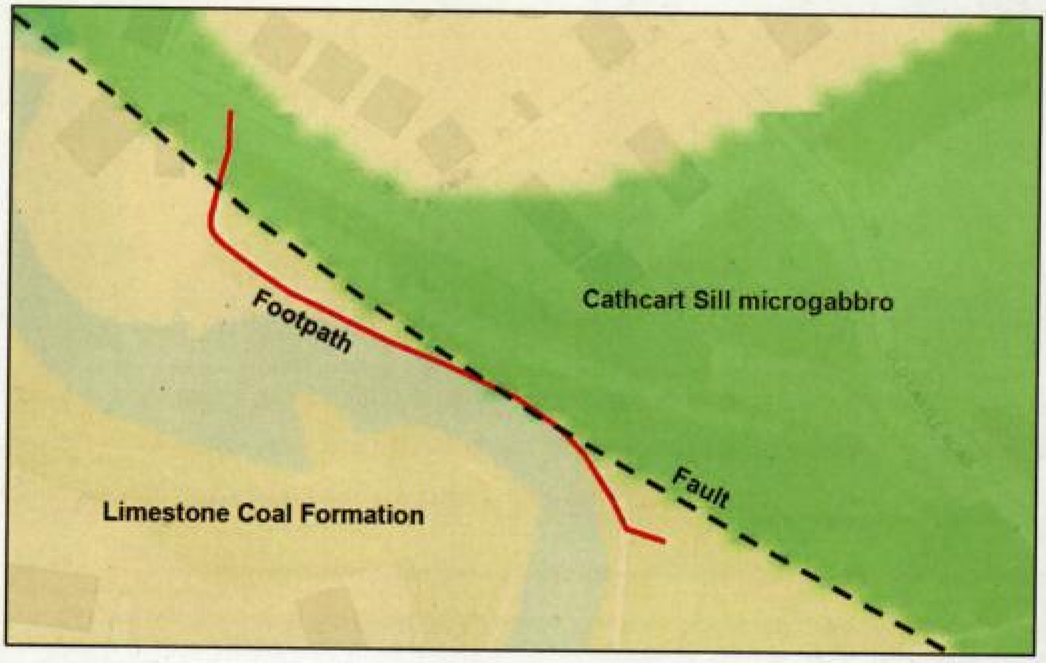
Chainage of rock fall 115m

Publicly available British Geological Survey (BGS) records indicate that the craggy escarpment if formed from the Cathcart Sill, an olivine-microgabbro igneous intrusion of late-Carboniferous/early-Permian age. In BS5930 this rock type is identified as Dolerite.

The southeasterly margin of the Sill is mapped as a faulted contact with adjacent Carboniferous sedimentary country rocks (Limestone Coal Formation) and the location of the fault is mapped approximately congruent with the footpath at the crag toe.

Whilst Devensian Glacial Till is present across the wider area, it is absent from the crest of the crags in question where it has been removed by erosion.

Figure 2: Annotated extract of BGS bedrock mapping showing footpath location



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3 GEOTECHNICAL INSPECTION

3.1 Inspection details

Inspection activities were carried out by RSK on 7th December 2021.

Details of the rock mass, rock condition and discontinuities visible on exposed rock faces were recorded in accordance with BS5930-2015:+A1-2020 Code of Practice for Ground Investigations and BS EN ISO 14689-1: 2003 Geotechnical investigation and testing.

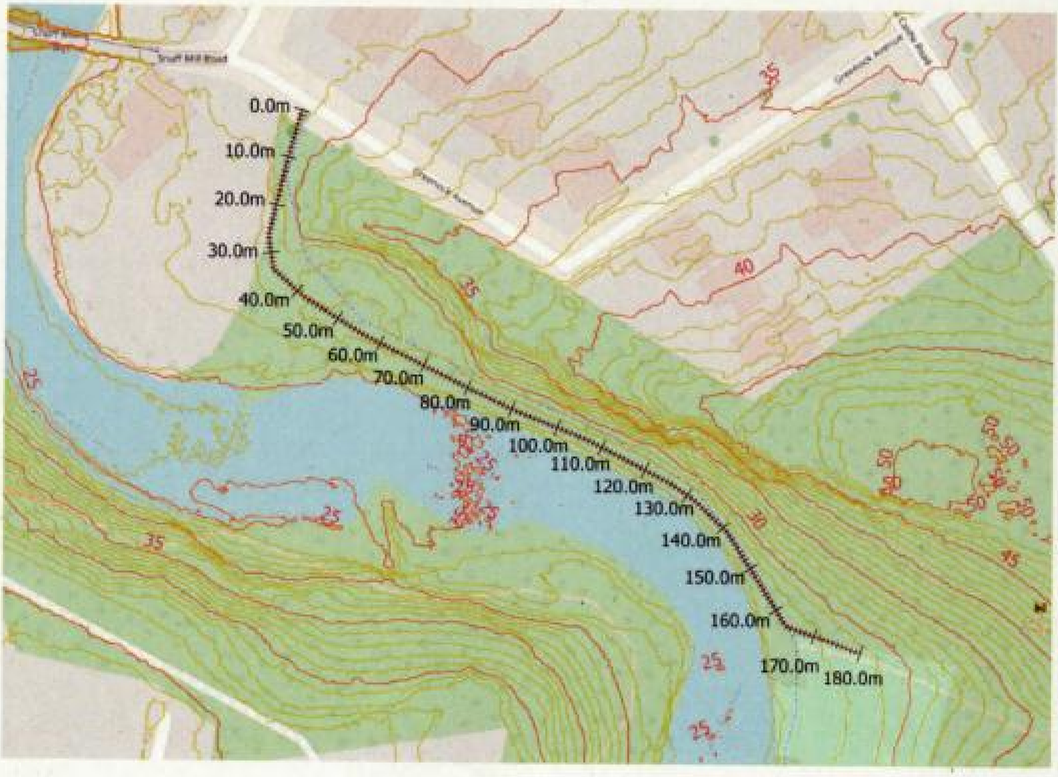
Rock descriptions and weathering grades were applied to classify the rock, whilst dip and dip direction readings of the discontinuity surfaces were taken.

3.2 Topographic data and chainage

At the time of writing, no site specific topographic survey has been commissioned. For the purposes of this assessment RSK have obtained publicly available Lidar and digital terrain model data from the Scottish Government's *Scottish Remote Sensing Portal* website (https://remotesensingdata.gov.scot/) (**Figure 3**). The elevation data shown on the remote sensing plans is consistent with that presented on Ordnance Survey mapping.

Inspection observations have been recorded with reference to a chainage (in metres) measured along the footpath at the toe of the escarpment from the gated entrance to the footpath adjacent to Greenock Avenue (chainage 0). The chainage extends southeastwards along the footpath to chainage 180 m, close to the confluence of the footpaths to the south of the remains of Cathcart Castle, as shown on **Figure 3**.

Figure 3: Plan showing terrain data and chainage.



3.3 Geomorphology

The escarpment is formed from a rocky ridge that trends northwest-southeast and increases in elevation from 35 m in the northwest to 50 m in southeast. The footpath elevation at its toe remains fairly constant at 28 m to 29 m (**Figure 3**).

Observations and measurements from the inspection have been combined with the terrain data outlined above to divide the escarpment into a number of geomorphic units, delineated by chainage. Cross sections through the units have been derived from the Lidar data and are shown together with a base plan in **Appendix B**.

3.3.1 Chainages 0 m to 30 m

From the footpath, this section comprises an approximately 12 m long 15° degree slope with a cover of soil and mature trees, which rises into a 40° to 50° slightly craggy slope with limited rock exposure due to a ground covering of ivy, ferns, moss and leaf litter. The rock mass shows persistent planar intersecting joints at the scale of exposure. The slope rises to a height of approximately 6 m above the adjacent footpath, with the steeper craggy section occupying the upper 2.5 m to 3.0 m (**Figures 4a** and **4b**).

No evidence of instability was observed in this section. Two rock blocks of maximum dimensions 440 mm x 300 mm x 370 mm were present near the toe of the slope adjacent to the path, but there was no evidence that these had fallen and are likely to be blocks that have historically been placed there.

Figure 4a: General view of Chainage 0 m to 30 m

Figure 4b: Jointed rock exposure near the crest of chainage 15 m

3.3.2 Chainages 30 m to 77 m

From chainage 30 m the footpath turns through an angle of approximately 100° to trend in a southeasterly direction. Between these chainages there is a re-entrant like feature within the escarpment, which may be the result of historical quarrying as rock is well exposed here.

At either end of this feature the distance from the footpath to the crags (the stand-off) is approximately 7.5 m and at its centre the stand-off is up to 11.7 m. At either end the ground slopes gently at 5° from the footpath to the toe of the escarpment, but in the centre, there is a low rocky outcrop (1m high above the adjacent footpath), beyond which the ground forms a 10 m wide shallow depression up to the base of the escarpment. This area is covered with abundant small tree growth (**Figure 5a**).

The lower part of the slope is 2 m to 3 m in height, stands at 40°, and is covered by soil and vegetation. It is not clear whether this is a debris slope of spalled rock as it is completely obscured.

Above the lower slope, ivy and moss covered rocky crags some 4.5 m high are exposed. Abundant rock structure (joints, discontinuities) is evident, with the very steeply dipping rock face being largely controlled by the orientation of major rectilinear joints dipping at angles up to 70° (**Figure 5b**) (see **Section 3.4.1**).

The elevation of the crest increases towards the southeast and there is abundant small tree growth at the crest.

Figure 5a: General view of chainage 30 m to 77 m

Figure 5b: Moss and ivy covered well-jointed rock crags at chainage 55 m

Rock structure is described as being NOT massive as it is at the Court Knowe rock face

At chainage 75 m the rock mass is affected by structural disturbance. A zone over a few metres comprised a mineralised vein zone with parallel close spaced fractures (100 mm to 200 mm spacing) cutting across the structure and dipping at 40° towards 310° (NW). This may be a brittle fracture zone associated with the nearby fault; mineralised slicken lines are present on fracture surfaces indicating movement perpendicular to the face. Due to the limited exposure it is unclear how far this feature extends through the rock mass, but it appears limited in nature and is unlikely to be a significant feature.

3.3.3 Chainages 77 m to 90 m

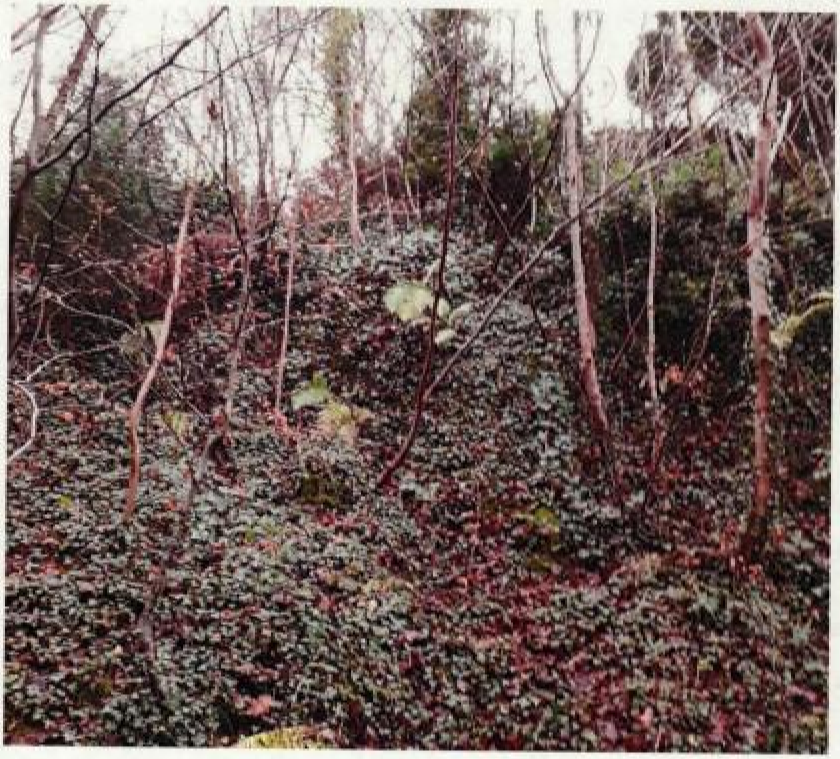
Past the re-entrant feature, the slope is dominated by an approximately 6 m high 40° slope whose toe directly adjoins the footpath. This slope is covered by soil and is vegetated with trees, ferns and ground-hugging ivy (**Figure 6a**). Occasional exposures of rock on a scale of 500 mm are seen through the soil covering; it is unclear whether this material is in situ, but is most likely made up of rocky debris.

Experience suggests that it is in situ and NOT debris.

At the top of the 40° slope, the ground steepens into crags with a height of approximately 4 m. This upper part of the slope appears to be rock outcrop, with ivy and moss covered exposures, but the slope is almost completely obscured by vegetation (**Figure 6b**).

Figure 6a: General view of lower slope at chainages 77 m to 90 m

Figure 6b: Ivy covered steep crags at top of lower slope at chainage 90 m



3.3.4 Chainages 90 m to 135 m

From chainage 90 m, the rock crags forming the upper part of the slope start to become more prominent, and by chainage 105 m are well developed. The lower slope adjoining the footpath steepens up to 50° and reduces in height to approximately 2 m to 3 m above the footpath. Above this, very steep ivy covered rock crags are visible up to approximately 11 m above the footpath, above which the slopes are obscured by vegetation (**Figure 7a).**

The rock fall was at chainage 115 m.

These are the two largest boulders to descend

A 4 m to 5 m high failure scar is present on the rock face above the lower slope at chainage 115 m (**Figure 7b**). The failure scar is formed from intersecting planar joint surfaces dipping very steeply (approximately 70°) out of the face. This is the site from which the recent rock falls have occurred. Two large rocks of maximum dimensions 600 mm x 450 mm x 350 mm were present on the footpath at the time of the inspection. It is not clear whether these were further rock falls or uncleared remnants of the earlier rock fall.

From chainage 120 m, the lower slope height begins to increase again, obscuring the craggy rock exposure above. Slope heights here appears to reach up to 16 m height above the path, but the upper slopes are obscured by vegetation.

Figure 7a: General view of lower slopes between chainages 90 m and 135 m

Figure 7b: Recent failure scar on intersecting joints at chainage 115 m

This is the short crag which has fallen down. The creation of the crag by erosion of the underlying material was first noticed some twenty years ago.

It was then expected that the crag would break away and slide slowly to the path - which is what happened over a few days.

3.3.5 Chainages 135 m to 180 m

From chainage 135 m, the lower slope increases in elevation and slackens back to an angle of 40°. The lower slope becomes a much longer feature, dominating the escarpment, with the rocky clag exposures confined to the uppermost 4 m of slope. At chainage 160 m the slope is 30 m long and this slope has abundant tree cover. The slope gradually increases in height to in excess of 20 m above the level of the footpath.

Rock crags are exposed at the top of the slope and are either inter-built with or built on with stone walls associated with the ruins of the historic Cathcart Castle.

The rocks exposed at the crest here are competent and generally unweathered in contrast to the northwestern part of the section. Presumably this is because weathered material was removed when the walls were constructed.

Figure 8a: General view of lower slopes at chainage 140 m

There is no visual evidence of the creation of other crags.

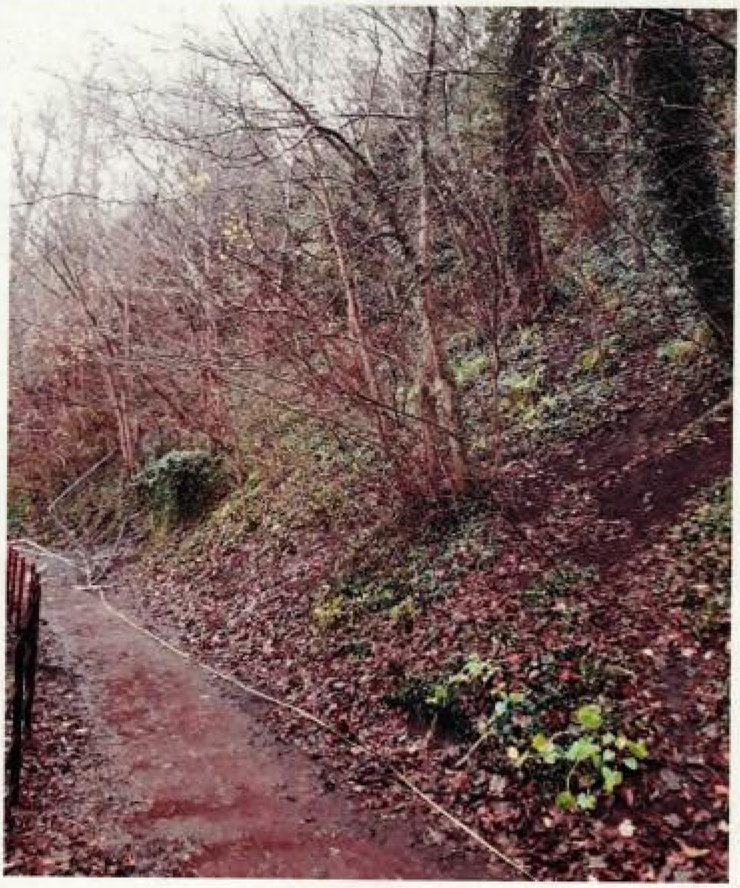


Figure 8b: View of slopes at chainage 170 m

3.4 Rock material and mass description

The exposed rock within the craggy escarpment comprised strong to very strong massive black to dark grey crystalline medium-grained MICROGABBRO with millimetre sized olivine phenocrysts visible in some fresh surfaces.

It is similar in nature to the rock face at Court Knowe which is mainly massive with some smaller jointing

It is likely that this structure is repeated below the Castle.

The rock mass is well jointed (See **Section 3.4.1**) but also contains numerous random fractures that reduce the size of joint-bound blocks. Joint-bound blocks are generally medium sized (average length of block sides 200 mm to 600 mm) and are prismatic to equidimensional in shape (**Figure 9**).

In the main, the exposed rock faces appear little weathered, with only minor brown discolouration and limited reduction in strength. In some areas the olivine phenocrysts can be seen to have decomposed to form brown iron-oxides, but this has not led to significant decomposition or strength reduction of the rock material.

The degree of weathering increases significantly towards the crest of the escarpment, although the rock face is largely obscured by vegetation. In areas where the face at the crest can be inspected, there is a distinct increase in the intensity of fracturing/jointing and a reduction in intact rock strength, with pale brown discolouration. Root penetration has clearly played a significant role in mechanical weathering of the rock mass, with woody roots causing significant close spaced fracturing of the rock (**Figure 10**).

Figure 9: Jointed and fractured dark grey microgabbro

Figure 10: Root penetration, weathering and fracture increase at the slope crest

3.4.1 Discontinuities

Within the restrictions of the limited rock exposure, it was possible to discern that the rock mass is systematically dominated by sub-vertical/steeply dipping regular sets of medium to wide spaced joints, with spacings of between 300 mm and 700 mm, but more generally 400 mm to 500 mm. These joints intersect, resulting in rectilinear or polygonal columns (columnar jointing), which are persistent at the scale of the exposure (**Figure 11**).

In general, two joint sets appear to dominate the structure of the exposed rock mass:

1) Dipping between 62° and 80° toward 140° to 178° (average 160°, i.e. SSE)
2) Dipping between 50° and 70° towards 218° to 280° (average 246°, i.e. WSW)

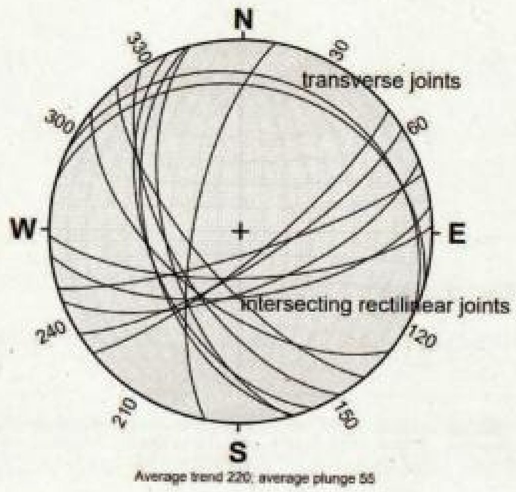
These joint sets have an average intersection at 220° (i.e. towards the southwest) and average plunge of 55°.

A summary of the discontinuity sets and intersections are shown as a lower hemisphere equal area stereographic projection in **Figure 12**.

Figure 11: Steeply dipping intersecting joints forming rectilinear columnar structures

This section is generic and based upon aerial survey information

Figure 12: Stereographic projection displaying the discontinuity sets present across the site



In some areas, where observable, the rock columns were fractured by regular close to medium spaced (100 mm to 300 mm) transverse joints, breaking the columns into a series of regular, roughly equidimensional prismatic blocks.

These transverse joints are generally at right angles to the main columnar joints and generally dip at 20° to 25° towards 015° to 025° (i.e. into the face towards the NNE). In general, all joint surfaces are straight, planar and rough, generally clean with some brown surface staining and devoid of mineral coatings.

Towards the crest of the slope transverse joints have been exploited by weathering to form loose, open fractures, with an increased fracture frequency and close spacing (**Figure 13**).

Figure 13: Open close spaced transverse jointing of rock columns at crest of slope

Before reading Section 4 go and take a look at the rock face at Court Knowe where all the vegetation has been removed.

4 STABILITY ASSESSMENT

4.1 Introduction

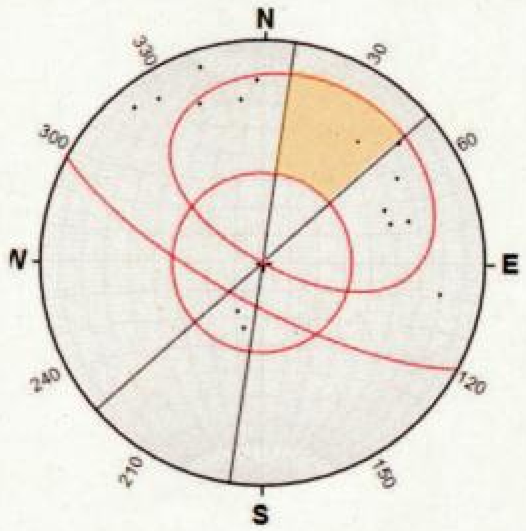
The properties of the rock mass are critical to determining the nature of instability (if any) that is present on a rock slope. Where slopes are formed in rocks with a high material strength (medium strong or stronger) the stability of the slope is largely controlled by discontinuities present in the rock mass and material strength is a secondary factor. Where slopes are formed in rocks with a low material strength (weak or weaker) the stability of the slope is controlled by a combination of material strength and discontinuities.

In discontinuity controlled rocks, kinematic analysis is used to identify feasible instability mechanisms (sliding, edge failure and toppling) in rock by assessing the orientation of discontinuities and how they would interact with the cliff face.

The average orientation of the escarpment rock face is dipping at around 70º to 75º towards 208º (i.e. SSW). This orientation has been used to undertake the kinematic stability assessments. Whilst this orientation changes at the northwestern and southeastern ends of the section, the inspection has shown that the exposed rock outcrops in these areas are of very limited extent with little structural control evident and are highly unlikely to be affected by discrete structural failure.

4.2 Plane instability

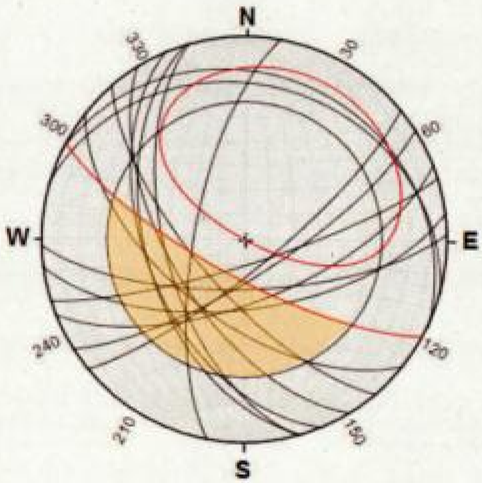
The analysis clearly shows the dip of the joints is well above the friction angle of the sliding plane. Only joint set 2 (dipping WSW) marginally falls within the sliding instability field. Therefore, it is considered that sliding is unlikely to be a significant failure mechanism at the site. Notwithstanding the above, the exposures demonstrate that given the appropriate orientations, small-scale sliding of loosened column masses may be feasible (e.g. **Figure 13**).



The roots of trees are probably what triggered the wedge failure - viz push the individual rock boulders out.

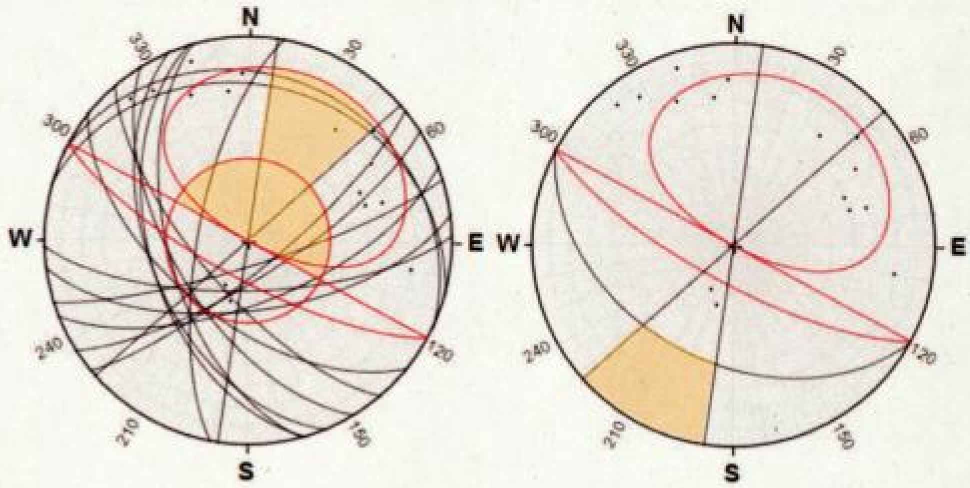
4.3 Wedge instability

The kinematic analysis clearly shows that the rectilinear joints intersect within the critical failure field. Wedge failure is therefore viable. Indeed, observations of the failure surface at chainage 115 m indicate that these steeply dipping intersecting joints have formed the failure surface for the recent rock fall events. Elsewhere, apparent historic failures may be evidenced by residual edge material constrained between the intersection joints (e.g. **Figure 11**).



4.4 Toppling instability

Kinematic analyses indicate that toppling (both direct and flexible) are unlikely to be feasible modes of failure based on the available discontinuity data.



4.5 Other failure mechanisms

4.5.1 Ravelling Failure

A fourth common failure mechanism is ravelling failure, which applies to smaller-scale, more superficial rock fall of small blocks delimited by joints on the slope and lacking a defined failure mechanism.

From the geotechnical inspection observations, it is clear that ravelling failure is likely to occur in the uppermost parts of the rock escarpment where weathering and tree-root action have significantly reduced the spacing and increased the frequency of fracturing to form smaller, more irregular rock blocks. In many cases rock blocks have been disturbed by root activity, reducing discontinuity strength parameters to residual values.

4.5.2 Composite Failure

Where a failure geometry is repeated frequently throughout a rock mass, or more than one failure geometry is present within a localised volume of the rock mass, it is possible for composite failure to occur. In the former case, the composite failure is made up of a "family" of failures of the same mechanism but differing in size. In the latter case, different failure mechanisms interact to produce a composite geometry that is the limiting geometry in terms of stability.

Observation from the geotechnical inspection indicate that composite failure of rectilinear wedges is feasible, and that the rock mass within the potentially failing wedge may be liable to ravelling failure.

5 STABILITY RISK ASSESSMENT

From the foregoing discussion it is clear that a number of feasible rock slope instability hazards have been identified at the site, and that indeed some of these instabilities have been realised, as evidenced by the recent rock falls identified around chainage 115 m.

The principal instability hazards identified are wedge failure/composite failure of rectilinear wedges, with ravelling failure of the unstable wedge material, and ravelling failure of the fractured/weathered crest materials at the top of the escarpment. The crest materials are also liable to direct failure and rock fall through the process of "root jacking" due to the significant vegetation and trees at the escarpment crest.

The identified hazards are located within the steeply dipping/near vertical rock crags that make up the upper sections of the escarpment. Due to the significant vegetation cover (trees, shrubs, ivy, moss, ferns) that obscures the majority of the slope, only limited areas of direct rock exposure were available for inspection. However, from the observations, it must be considered that the identified hazards pertain across the majority of the rock face as the rectilinear jointing is systematic and the crest materials are all likely to have been affected by weathering and root action to some degree. It is also possible that localised features such as faults/discrete fracture zones could be present, but were not revealed by the inspection due to the lack of exposure.

On the basis of the foregoing discussion, a qualitative risk assessment has been carried out for each chainage section based on the slope morphology, presence of the identified hazard and the likelihood that failed material could reach receptors using the footpath.

Each slope was given a relative risk rating of **HIGH**, **MODERATE** or **LOW**.

Table 1: Description of risk

The frequency of occurrence of the hazards have NOT been defined.

It is this which in safety terms is critical.

Risk	Description
LOW	Areas where the hazard is unlikely to be realised or where there is a very low likelihood of failed material reaching the footpath.
MODERATE	Areas where the hazard is likely be realised but where there is a low likelihood of failed material reaching the footpath.
HIGH	Areas where the hazard is likely be realised and where there is a moderate to high likelihood of failed material reaching the footpath.

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Table 2: Rock Fall Risk Assessment

Chainage	Length (m)	Slope characteristics	Hazard	Distance from hazard to receptor (footpath)	Qualitative risk rating	Reasoning for risk level
0 – 30	30	15° wooded slope to low crag	None specifically identified	12 m	LOW	No direct evidence of instability
30 – 77	47	Re-entrant with steep rocky crags	Ravelling and wedge failures/composite failures	7 m to 11 m	MODERATE	Potential for instability & public access area
77 – 90	13	6m high 40° slope with subdued vegetated rocky crags above		Approx. 8 m down 40° slope	MODERATE - HIGH	Potential for instability and rocks will roll down to footpath
90 - 135	45	3m high 50° slope with prominent steep rock crags above. Area of failure.		Approx. 2.6 m down 50° slope	HIGH	Evidence of instability & effectively no stand-off
135 - 180	45	High 40° wooded slopes with long limited rock crags and old stone walls at crest	Potential for ravelling	Approx. 30 m down 40° slope	LOW	Potential for localised instability at crest/stone wall but long run out distance for falling debris

The history of rockfalls over the last 100 years would tend to indicate a much lower rating .... it is suggested that Low might be used everywhere except for 90 to 135 which might be better described as "occasional".

6 OPTIONS APPRAISAL

The purpose of conducting the above risk assessment is to provide reference data for use in a risk management and reduction strategy. Depending on the level of risk identified, there are two main options to address the issue of instability:

- Management of the risk by inspection/monitoring and, if required, maintenance; and
- Engineering intervention.

There are four general engineering approaches for risk reduction with remedial and mitigation works:

1) Containment – *involves allowing failures to occur but containing the failed material within a designed area, to reduce or minimise the risk. Containment involves passive rock netting, barriers and rock traps.*
2) Strengthening – *involves the introduction of elements into or only to the rock mass to increase its strength. Strengthening includes active rock netting, reinforcement and support.*
3) Removal – *involves removing unstable rock masses to achieve risk reduction. Removal involves scaling and re-profiling.*
4) Avoidance – *involves bypassing high risk rock slopes by re-routing paths, fencing or creating stand-off areas, therefore minimising the risk by avoiding it.*

Table 3 presents an initial assessment of the available options based on the risk rating and the most appropriate/practical risk reduction/management methods.

This is the key table to the report.

It is suggested that alternative opinions be sought.

Table 3: Assessment of most appropriate/practical risk reduction options

Chainage	Qualitative risk rating	Remedial Option				Manage by routine inspection	Do Nothing
		Containment	Strengthening	Removal	Avoidance		
0 - 30	LOW	×	×	×	×	×	✓
30 - 77	MODERATE	×	×	×	✓	✓	×
77 - 90	MODERATE - HIGH	✓	✓	✓*	×	×	×
90 - 135	HIGH	✓	✓	×	×	×	×
135 - 180	LOW	×	×	×	×	✓	×

Note: * May be possible, dependent on detailed inspection after vegetation clearance

Table 4 presents a more detailed assessment of the most appropriate mitigation/remedial options, where required, an assessment of their respective merits and estimated costs and timescales for construction. In this way, the adopted strategy is designed to allow GCC to access allocation of resources to achieve cost effective risk mitigation and management such that, as far as is practically possible, the public are not exposed to unacceptable levels of rock fall risk.

An experienced geologist with intimate knowledge of Linn Park going back over forty years comments as follows:

The obvious solutions are:

1) A barrier to falling rocks, but the path is too near the cliff to be effective. Path could be moved into river, but narrowing of channel probably taboo, due to flooding issues.

2) Netting/rock bolting. May need removal of trees, etc, which would worsen stability.

Assuming both the above options are too expensive for Council to contemplate:

a) Fencing will always be open on the river side, so path closure is not fully effective.

b) In the unlikely event that somebody is injured, they could lie for a long time. Whereas, if the path was open, (at walker's own risk) folk pass regularly.

Some comments by the Linn Park Gentlemen's Walking Club [one of whom has been using the park since he was 5 years old] - mostly Chartered Engineers - who have approached the problem on what might be described as the comparative risks of doing and not doing something.

Their considered conclusion is that it is much safer to leave the path OPEN.

They make two observations:
1) For forty years no rocks ever fell down - except in the Court Knowe quarry - go and count them.
2) What is the likelihood of a rock fall in the next decade ?

The comparative risks which ought to have been considered are:
a) Bicyclists being forced to use the very narrow part of Old Castle Road past the Castle as opposed to being safe on the path below the Castle,
b) Pedestrians unfamiliar with the area find themselves unable to walk the path below the Castle, coming out at Seil Drive and walking down the very narrow part of Old Castle Road past the Castle.
c) Park users who consider it safe to walk below the Castle AND negotiate the fence jutting out over the river.

It is noted that there are a considerable number of places in Linn Park where risks exists and have been accepted - which may carry a higher "risk factor" than another rock fall.

Table 4: Options Appraisal

Applicable to	Remedial options	Advantages	Disadvantages	Buildability	Estimated cost and timescale
Chainages 30m to 77m	***Avoidance:*** Install a standard 1.8m high chain link fence across the face of the re-entrant feature, add signage as to the risk of falling rocks	Non-specialist materials required (e.g. chain link fence) Can be installed cheaply by local trades/GCC trades Minimal maintenance required Prevents public access from the footpath (breaks the link between hazard and receptor)	Public perception of loss of amenity/negative PR Public access may still be available via the crest if public ignore signage	Easy access to this location via Greenock Avenue. No specialist or large-scale plant required.	[redacted] [redacted] [redacted]
	Manage by routine Inspection: Routine survey to monitor the condition of the rock face. Add signage as to	Could be undertaken by GCC engineering representative, seeking specialist advice only if required.	Does not prevent public access	Not applicable	[redacted] [redacted]

Applicable to	Remedial options	Advantages	Disadvantages	Buildability	Estimated cost and timescale
	the risk of falling rocks	Lowest cost option	Does not remove the hazard but monitors it and warns the public Maintenance of the rock face may still be required in the future, dependent upon results of on-going monitoring		
Chainages 77m to 135m	***Containment:*** Install a passive mesh system (drapery) on the rock face	Mesh curtain allows material to fail but contains it behind the mesh (breaks the link between hazard and receptor) Low/negligible visual impact once vegetation has re-grown	Requires initial de-vegetation and scaling of the rock face to be protected by rope-access specialists Requires maintenance visits (approx. every 2 - 5 years dependant on conditions) to remove material caught behind the mesh. Likely to require some degree of vegetation clearance to access mesh	Restricted access to toe along footpath and at slope crest No access for heavy drilling plant to drill crest and toe anchors Requires restricted access equipment. Increased construction timescale	[redacted] [redacted] [redacted]

That over the last 40 years no material has fallen down the cliff tends to suggest that the proposed remedial works have been "over suggested"

Applicable to	Remedial options	Advantages	Disadvantages	Buildability	Estimated cost and timescale
		Cheaper than active systems	Site users may perceive risk as material fails from the face/negative PR		
	Containment: Install a rock fall catch fence at the toe of the slope adjacent to the footpath	Catch fence allows material to fail but contains it behind the fence (breaks the link between hazard and receptor)	Requires maintenance visits (approx. every 2 - 5 years dependant on conditions, or when rock fall is reported to have occurred) to remove material caught behind the fence	Access only required to toe of slope. Standard small plant can be used to drill fence post anchors.	[redacted] [redacted] [redacted] [redacted]
		No initial de-vegetation and scaling of the rock face required	Site users may perceive risk as material fails from the face/negative PR		
		Easy access for maintenance			
	Reinforcement: Install an active reinforced mesh system on the rock face	Rock dowels and tensioned mesh prevent material from failing from the rock face and retains it in situ (removes hazard)	Requires initial de-vegetation and scaling of the rock face to be protected	Restricted access to toe along footpath and at slope crest No access for heavy drilling plant	[redacted]

Applicable to	Remedial options	Advantages	Disadvantages	Buildability	Estimated cost and timescale
		Low/negligible visual impact once vegetation has re-grown Requires minimal maintenance	Likely to require some degree of vegetation clearance to assess mesh as part of maintenance	Requires restricted access equipment – "A"-frame rig suspended from crest access system Longest/increased construction timescale	[redacted]
Chainages 135m to 180m	***Manage by routine inspection***: Routine survey to monitor the condition of the rock face/historic stone wall	Could be undertaken by GCC engineering representative, seeking specialist advice only if required.	Does not prevent public access Does not remove the hazard but monitors it Maintenance of the rock face may still be required in the future	Not applicable	[redacted]

7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

The rock face from which recent rock fall has been reported forms part of a heavily vegetated 180 m long rocky escarpment that trends northwest-southeast and increases in elevation from 35 m in the northwest to 50 m in southeast. The footpath elevation at its toe remains fairly constant at 28 m to 29 m.

The inspection identified that the rocky crags are formed from an olivine-microgabbro sill, comprising a well-jointed and fractured strong to very strong rock mass. Weathering of the crest was locally observed, with a distinct increase in the intensity of fracturing/jointing and a reduction in intact rock strength, associated with root penetration.

Discontinuity assessment reveals two systematic sets of steeply dipping intersecting joints, which form rectilinear or polygonal columns. Kinematic analyses indicate that these columns are liable to wedge failure, with ravelling failure of the unstable wedge material. In addition, despite the lack of exposure due to vegetation, ravelling failure of the fractured/weathered crest materials at the top of the escarpment is feasible. The crest materials may also be liable to direct failure and rock fall through the process of "root jacking" due to the significant vegetation and trees at the escarpment crest.

There are several geomorphic units, which present different levels of risk to the public using the footpath. The highest risk area is present between chainages 77 m and 135 m (the recent rock fall is recorded at chainage 115 m), where there is little to no effective stand-off distance between the rock fall hazard and the footpath.

A risk assessment and options appraisal has identified the following sections and most appropriate/practical management/remedial options:

- Chainage 0 m to 30 m: Low Risk; Do nothing;
- Chainage 30 m to 77 m: Moderate Risk; install standard fencing and signage to deter public access OR monitor the on-going situation by periodic inspection, and take action where and when necessary;
- Chainage 77 m to 135 m: High Risk; install a containment or reinforcement system; and
- Chainage 135 m to 180 m: Low Risk; monitor the on-going situation by periodic inspection, and take action where and when necessary.

This recommendation requires to be revised as the historical record of falls which has not been researched but local knowledge [of 40 years] tends to refute.

7.2 Recommendations

For the High Risk area between chainages 77 m and 135 m, a decision should be made as to the most appropriate and cost effective remedial solution.

A catch fence placed along the toe of the slope appears to be the most favourable option in terms of ease of construction and maintenance. For this option, as there is no installation on the rock face itself, vegetation clearance and rock face scaling can be avoided, causing minimum disruption.

To progress this option, computational rock fall analyses will need to be undertaken to determine potential falling rock path trajectories and energies to determine appropriate fence height and energy rating and to ensure all possible rock fall paths can be captured using this option.

Notwithstanding the above, given the lack of rock exposure due to the significant vegetation cover, it is recommended that at the detailed design stage some limited vegetation clearance and face inspection is undertaken in vertical strips by a competent geotechnical rope access contractor to ensure the expected conditions pertain.

In addition, at detailed design stage, it is recommended that some limited topographical surveying is undertaken to ensure the elevations and extents of the publicly available Lidar data used in this assessment are accurate/valid.

RSK GEOSCIENCES

APPENDIX A
SERVICE CONSTRAINTS

1. This report and the site investigation carried out in connection with the report (together the "Services") were compiled and carried out by RSK Environment Limited (RSK) for Glasgow City Council (the "Client") in accordance with the terms of a contract [RSK Environment Standard Terms and Conditions] between RSK and the Client. The Services were performed by RSK with the reasonable skill and care ordinarily exercised by an environmental consultant at the time the Services were performed. Further, and in particular, the Services were performed by RSK taking into account the limits of the scope of works required by the client, the time scale involved and the resources, including financial and manpower resources, agreed between RSK and the Client.
2. Other than that, expressly contained in paragraph 1 above, RSK provides no other representation or warranty whether express or implied, in relation to the Services.
3. Unless otherwise agreed in writing, the Services were performed by RSK exclusively for the purposes of the Client. RSK is not aware of any interest of or reliance by any party other than the Client in or on the Services. Unless expressly provided in writing, RSK does not authorise, consent or condone any party other than the client relying upon the Services. Should this report or any part of this report, or otherwise details of the Services or any part of the Services be made known to any such party, and such party relies thereon that party does so wholly at its own and sole risk and RSK disclaims any liability to such parties. **Any such party would be well advised to seek independent advice from a competent environmental consultant and/or lawyer.**
4. It is RSK's understanding that this report is to be used for the purpose described in the introduction to the report. That purpose was a significant factor in determining the scope and level of the Services. Should the purpose for which the report is used, or the proposed use of the site change, this report may no longer be valid and any further use of or reliance upon the report in those circumstances by the client without RSK 's review and advice shall be at the client's sole and own risk. Should RSK be requested to review the report after the date of this report, RSK shall be entitled to additional payment at the then existing rates or such other terms as agreed between RSK and the client.
5. The passage of time may result in changes in site conditions, regulatory or other legal provisions, technology or economic conditions which could render the report inaccurate or unreliable. The information and conclusions contained in this report should not be relied upon in the future without the written advice of RSK. In the absence of such written advice of RSK, reliance on the report in the future shall be at the Client's own and sole risk. Should RSK be requested to review the report in the future, RSK shall be entitled to additional payment at the then existing rate or such other terms as may be agreed between RSK and the client.
6. The observations and conclusions described in this report are based solely upon the Services which were provided pursuant to the agreement between the Client and RSK. RSK has not performed any observations, investigations, studies or testing not specifically set out or required by the contract between the client and RSK. RSK is not liable for the existence of any condition, the discovery of which would require performance of services not otherwise contained in the Services. For the avoidance of doubt, unless otherwise expressly referred to in the introduction to this report, RSK did not seek to evaluate the presence on or off the site of asbestos, invasive plants, electromagnetic fields, lead paint, heavy metals, radon gas or other radioactive or hazardous materials, unless specifically identified in the Services.
7. The Services are based upon RSK's observations of existing physical conditions at the Site gained from a visual inspection of the site together with RSK's interpretation of information, including documentation, obtained from third parties and from the Client on the history and usage of the site, unless specifically identified in the Services or accreditation system (such as UKAS ISO 17020:2012 clause 7.1.6):

a. The Services were based on information and/or analysis provided by independent testing and information services or laboratories upon which RSK was reasonably entitled to rely.

b. The Services were limited by the accuracy of the information, including documentation, reviewed by RSK and the observations possible at the time of the visual inspection.

c. The Services did not attempt to independently verify the accuracy or completeness of information, documentation or materials received from the client or third parties, including laboratories and information services, during the performance of the Services.

RSK is not liable for any inaccurate information or conclusions, the discovery of which inaccuracies required the doing of any act including the gathering of any information which was not reasonably available to RSK and including the doing of any independent investigation of the information provided to RSK save as otherwise provided in the terms of the contract between the Client and RSK.

8. The intrusive environmental site investigation aspects of the Services are a limited sampling of the site at pre-determined locations based on the known historic / operational configuration of the site. The conclusions given in this report are based on information gathered at the specific test locations and can only be extrapolated to an undefined limited area around those locations. The extent of the limited area depends on the properties of the materials adjacent and local conditions, together with the position of any current structures and underground utilities and facilities, and natural and other activities on site. In addition, chemical analysis was carried out for a limited number of parameters (as stipulated in the scope between the client and RSK, based on an understanding of the available operational and historical information) and it should not be inferred that other chemical species are not present.

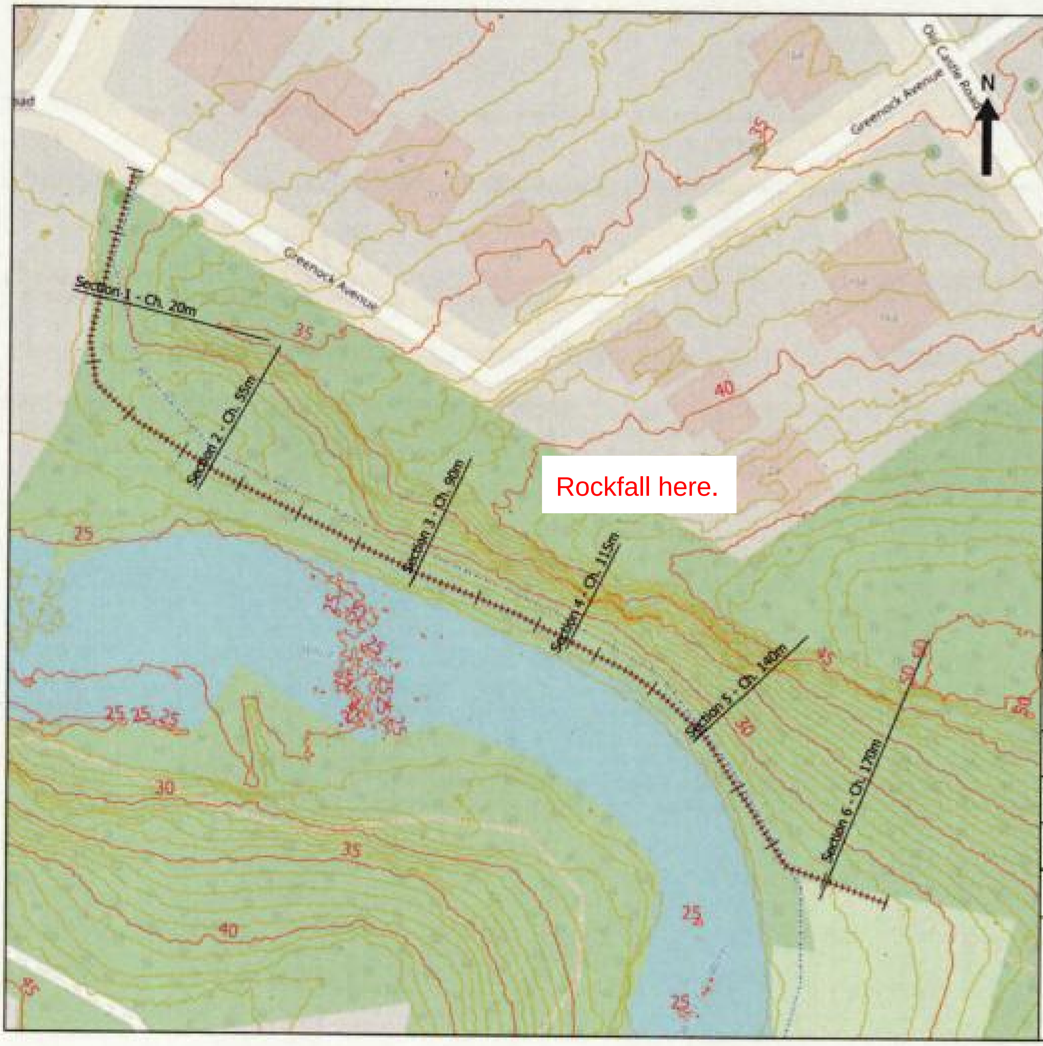
9. Any site drawing(s) provided in this report is (are) not meant to be an accurate base plan but is (are) used to present the general relative locations of features on, and surrounding, the site. Features (intrusive and sample locations etc) annotated on site plans are not drawn to scale but are centred over the approximate location. Such features should not be used for setting out and should be considered indicative only.

10. The comments given in this report and the opinions expressed are based on the ground conditions encountered during the site work and on the results of tests made in the field and in the laboratory. However, there may be conditions pertaining to the site that have not been disclosed by the investigation and therefore could not be taken into account. In particular, it should be noted that there may be areas of made ground not detected due to the limited nature of the investigation or the thickness and quality of made ground across the site may be variable. In addition, groundwater levels and ground gas concentrations and flows, may vary from those reported due to seasonal, or other, effects and the limitations stated in the data should be recognised.

11. Asbestos is often observed to be present in soils in discrete areas. Whilst asbestos-containing materials may have been locally encountered during the fieldworks or supporting laboratory analysis, the history of brownfield and demolition sites indicates that asbestos fibres may be present more widely in soils and aggregates, which could be encountered during more extensive ground works.

12. Unless stated otherwise, only preliminary geotechnical recommendations are presented in this report and these should be verified in a Geotechnical Design Report, once proposed construction and structural design proposals are confirmed.

APPENDIX B
TOPOGRAPHIC DATA



LEGEND

sections

Chainage

5m contours

1m contours

OpenStreetMap - base map

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Client

Glasgow City Council

Pro ect Title

Linn Park, G asgow

Drawing Title

Site plan

Drawn	Date	Checked	Date	Approved	Date
[redacted]	17.12.202	[redacted]	17.12.202	-----	-----

Scale	Orig Size	Dimensions
1:975	A4	m

Pro ect No	Drawing File
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Drawing No	Rev
Appendix B - Sheet 1	01

Sca e 1:778

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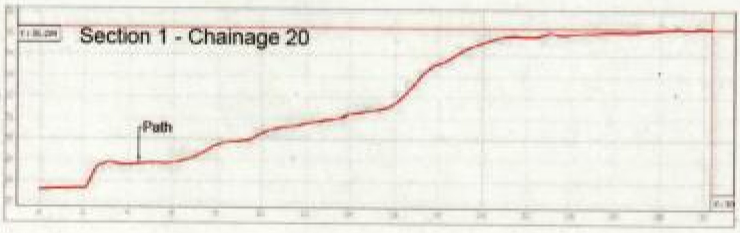
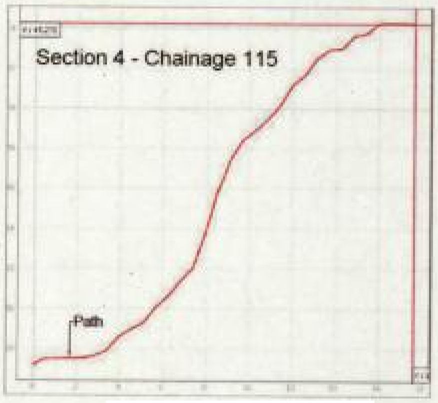
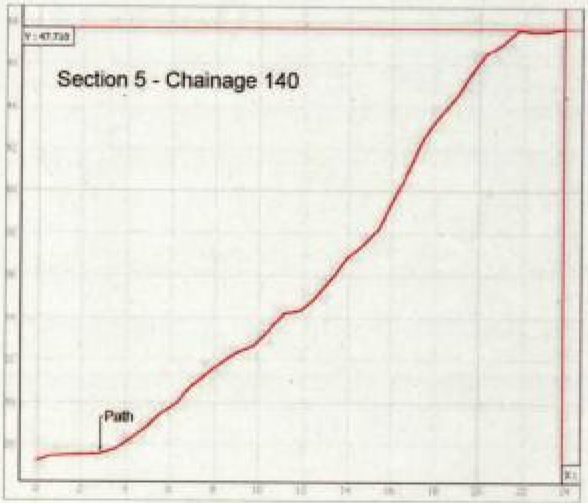
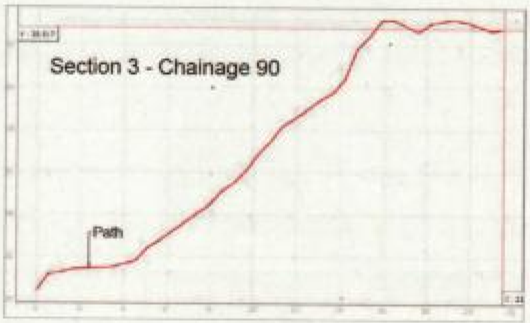
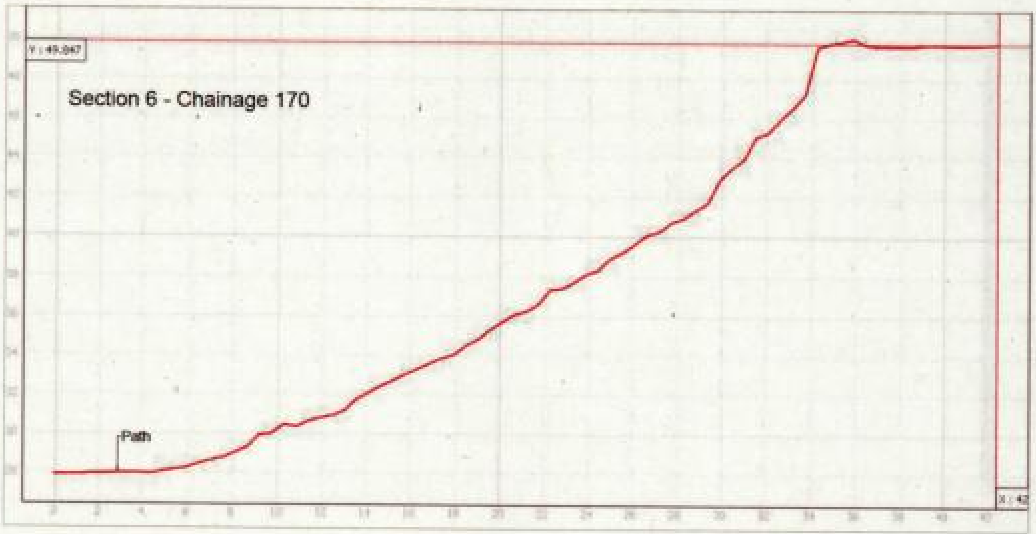




At the rockfall







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Client: GLASGOW CITY COUNCIL

Project Name: LINN PARK, GLASGOW

Description: SLOPE SECTIONS

Rev	Date	Amendment	Drawn	Chkd	Appd
01	21.12.21	FIRST ISSUE			

Dimension	Scale	Size	Revision	Project ID	Sheet	File name
m	NTS	A3	01	372568	01	372568-SLOPESECTIONS-REV01