CONTROL SHEET

CLIENT: Fife Council

PROJECT TITLE: Lochgelly South Primary School, Lochgelly, Fife

REPORT TITLE: Technical Note: Options, Rationale and Considerations for Mining Instability Mitigation

PROJECT REFERENCE:

DOCUMENT NUMBER:

Issue & Approval Schedule	<Issue 1> <STATUS>	Name	Signature	Date
	Prepared by	Project Mining Engineer	Signed copy held on file	29/04/2022
	Checked by	Principal Mining Engineer	Signed copy held on file	29/04/2022
	Approved by	Partner	Signed copy held on file	29/04/2022

Revision Record	Rev.	Date	Status	Description	Signature	
	1	16/11/22	DRAFT	Minor amendments	Prepared By	
					Checked	
					Approved	
	2				Prepared By	
					Checked	
					Approved	

Technical Note

Project: Lochgelly South Primary School Consolidation

Client: Fife council

Date: 29/04/2022

Options, Rationale and Considerations for Mining Instability Mitigation

1. Background

Following discussions with Fife Council, this technical note has been prepared in order to outline the mineral instability situation at the site of Lochgelly South Primary School, to provide an appraisal of the feasibility of undertaking remedial works to mitigate the hazard and to summarise the particular technical challenges and safety/environmental considerations.

Our previous desk-based research of the available geological information indicated that the site is underlain by rock strata belonging to the Limestone Coal Formation of the Carboniferous Period, dipping towards the east. Two formerly economic coal seams, namely the Lochgelly Splint and Lochgelly Parrot coals, outcrop at or around the school site (see appended Drawing No 148535/9003) and are inferred to underlie the school at shallow depths. Available mine plan and historic borehole evidence is strongly suggestive that the site is underlain by old uncharted workings in both of the aforementioned seams.

Our subsequent site investigation works, comprising two phases of boreholes sunk within the school grounds, confirmed the presence of old workings in both seams, in some cases comprising large voids up to 3.5 metres in height, indicating workings remaining open, and in others, broad zones of broken rock strata suggestive of workings in a state of partial collapse.

Table 1 below provides a summary of the findings of each exploratory hole and the hole locations are shown on Drawing No 148535/9003:

Table 1 – Borehole Results

BOREHOLE	*ROCKHEAD DEPTH*	*DETAILS*	*SEAM INTERPRETATION*	*TOTAL DEPTH*
BH01	2.0m	4.0m of BROKEN STRATA from 6.0m to 10.0m	Probable collapsed working in Lochgelly Splint Coal	21.0m
		3.0m VOID from 14.0m to 17.0m	Working in Lochgelly Parrot Coal	
BH02	2.0m	1.0m COAL from 6.0m to 7.0m	Lochgelly Splint Coal	21.0m

BOREHOLE	ROCKHEAD DEPTH	DETAILS	SEAM INTERPRETATION	TOTAL DEPTH
		3.5m VOID from 15.0m to 18.5m	Working in Lochgelly Parrot Coal	
BH03	2.0m	6.5m of BROKEN STRATA from 5.5m to 12.0m	Probable collapsed working in Lochgelly Splint Coal	21.0m
		3.0m VOID from 14.5m to 17.5m	Working in Lochgelly Parrot Coal	
BH04	-	Not drilled: access unavailable for rig at time of site works	-	-
BH05	6.0m	3.0m VOID/BROKEN STRATA from 11.0m to 14.0m and 1.3m BROKEN STRATA from 15.0m to 16.3m	Collapsed working in Lochgelly Parrot Coal with upward migration (Lochgelly Splint Coal "off")	21.0m
BH06	6.0m	3.0m SOFT / BROKEN STRATA from 6.5m to 9.5m	Uncertain: possible working in Lochgelly Splint Coal or disturbed strata associated with upward migration of Lochgelly Parrot workings	17.6m
		1.5m VOID from 10.5m to 12.0m	Lochgelly Parrot Coal	
BH07	7.5m	3.0m SOFT FILL / PARTIALLY BROKEN STRATA from 4.5m to 7.5m	Lochgelly Splint Coal worked at or close to outcrop (Lochgelly Parrot Coal not identified)	17.6m
BH07A (drilled at 30º from vertical from the position of BH7 and directed beneath the	7.8m (vertical depth when corrected for drilling angle)	"Soft Fill" noted within overburden at pavement depth of 7.8m	Possible waste or collapse within Lochgelly Splint working close to seam outcrop (Lochgelly Parrot Coal not identified)	15.2m (vertical depth when corrected for drilling angle)

BOREHOLE	ROCKHEAD DEPTH	DETAILS	SEAM INTERPRETATION	TOTAL DEPTH
school building				
BH08	2.0m	3.5m VOID from 2.5m to 6.0m	Working in Lochgelly Splint Coal (Lochgelly Parrot Coal not identified)	17.6m
BH09	2.2m	1.3m SOFT from 6.0m to 7.3m 2.7m BROKEN STRATA from 7.3m to 10.0m	Collapsed working in Lochgelly Splint Coal	17.6m
		0.8m VOID from 12.2m to 13.0m	Working in Lochgelly Parrot Coal	

NB. Depths are in metres below existing ground level

The old workings are at such shallow depths that they represent a surface stability hazard to the existing school building together with any future structural developments that may take place within the school site.

Therefore, the potential impacts of the mining-related instability, and the options and rationale for mitigative measures require to be outlined, particularly in relation to the difficulties presented by undertaking remedial works beneath the existing school building and in a generally restricted site.

2. Potential Mining Stability Hazards

Considering the likely age of the mine workings and the results of the mineral investigations at the site, we consider that the coal was most likely extracted via the stoop and room method of mining whereby passageways or “rooms” were driven into the seam with pillars or “stoops” of intact coal left to support the roof.

Where the stoop and room method was employed the pillars of coal often continue to support the roof for an indefinite period, maintaining the old workings in an open condition. However, over time the workings eventually fail by one of the following mechanisms, or a combination thereof:

- Roof failure: the most common type of failure, whereby the rock layers in the roof of the working become detached from the overlying strata and collapse to the working floor. This can result in a progressive upward collapse of the overlying rock strata until it is either choke filled or arrested by a competent stratum of rock, or it reaches the surface and manifests as a crown hole.

- Stoop failure: occurs when stoops deteriorate over time as a function of weathering or spalling of the stoop sides, reducing their ability to sustain the pressure from the overburden. Where stoop failure occurs it can lead to the collapse of the overlying strata resulting in localised surface ground movement. However, when the failure of a stoop leads to increased load on adjacent stoops, a “domino” effect can occur whereby several stoops fail, resulting in subsidence over a larger area in the form of broad bowl-shaped depressions.

- Floor heave: where the worked coal seam lies on top of a weak stratum such as a seatearth which is susceptible to swelling or heave, the load from the stoops can effectively lead to them punching through the floor of the workings, leading to a general lowering of the ground surface and differential settlement around the periphery of the impacted area.

The timescales for the above failure mechanisms cannot be predicted but all can lead to strains and damage to surface structures when the failure propagates to the surface and results in loss of support to the foundations and a resultant deterioration of the structure. Such damage commonly manifests as stepped cracking in brickwork and masonry, tilting of rooflines and lintels, floor damage and damage to pipework and other infrastructure. More significant building damage where the overall integrity of the structure is compromised as a result of failure within shallow mine workings is considered highly unlikely in this instance.

Given the current condition and depth of the old workings beneath the School site, we consider that the existing school building is at risk from compromised structural integrity as a result of collapsing mine workings at an unspecified time in the future. Therefore, mitigation measures are required to address these risks, these normally comprising the infilling of the workings with a cementitious grout via a series of injection boreholes.

3. Site-Specific Challenges

Under normal circumstances the immediate mitigation for the mining instability hazard would be to undertake drilling and grouting works to substantially fill the residual void space in both horizons of workings.

However, the mine workings disclosed by the investigation boreholes occur at particularly shallow depths, with the Lochgelly Splint Coal being recorded at pavement depths of between 6 and 10 metres in proximity to the school building and the Lochgelly Parrot Coal at pavement depths of between 12 and 16 metres. At such depths, consolidation by conventional drilling and grouting methodology is particularly challenging where required beneath an existing structure of the scale of the school building, due to the extreme borehole angles required to target the worked seam where it lies beneath the central part of the school. We have calculated that these angles may reach up to around 70 degrees from the vertical from borehole launch positions around the periphery of the building footprint.

Undertaking boreholes at such angles presents significant safety considerations for the specialist contractor in preventing injury to the drilling operatives when handling drilling rods and casings at inclinations beyond which conventional drilling equipment is designed for. The necessary modifications and changes in technique would likely result in significantly increased cost and timescales.

Moreover, where extreme angles are used in drilling to treat old mine workings, the risk of deflection of the drill string down the "path of least resistance" in response to hard strata or other obstacles is increased significantly, leading to a lack of certainty in the accuracy or the terminal position of the borehole and a resultant lack of confidence in the effective injection of grout. In addition, the workings have been found to be in a state of partial collapse within several of the investigation boreholes, with broad zones of broken strata frequently covering several metres in height. Inclined boreholes at extreme angles will result in grout injection at a singular depth which is unlikely to infiltrate the full height of the void space within the collapsing workings.

For the reasons stated above, we consider that any borehole locations requiring angles of greater than 45 degrees from the vertical should not be undertaken and alternative means should be sought.

In addition to the technical challenges surrounding the treatment of workings beneath the existing building, the following issues have been identified:

- Restricted access and confined working space in playground
- Works in residential area – interaction with local residents
- Control of grout placement to prevent excessive escape of grout outwith the treatment footprint in a down-dip direction.
- Programme constraints in relation to working within school summer holiday period.
- Control of drilling flush water and grout spillage on tarmac surface with high potential for runoff outwith site
- Control of dust
- Control of noise
- Vibration
- Monitoring and mitigation of mine gas risk in relation to school and neighbouring properties
- Reinstatement of playground surface to safe/useable condition post-works

4. Options for Mining Instability Hazard Mitigation

The following options have been derived in cognisance of published guidance on Mining Instability (Ref. 1) and have been the subject of discussions with Fife Council in relation to the project. The options presented are in many cases non-viable but are intended to illustrate that all scenarios have been considered.

4.1. Managed non-treatment

The school building is understood to have been constructed in the early 20th century and appears superficially to have suffered no adverse structural effects from mining related ground movement throughout its lifespan thus far. In certain circumstances consideration can be given to a regime of continuous ongoing structural monitoring, particularly since, with the exception of the proposed modular classroom which is external and separate from the main school building, no new structural development is proposed.

However, in light of the considerable height of the old workings (up to 3.5 metres of void space) and their particularly shallow depth where they underlie the site (pavement depths as shallow as 6 metres below ground level), we are of the opinion that while timescales cannot be predicted, future structural damage to the school building as a result of mining-related ground movement is inevitable and likely to be considerable, such that extensive repairs would be required, not to mention the remediation of the mining problem at that stage to prevent further damage. As such it is considered that the non-treatment of shallow mineworkings at the site is not a viable option and that more robust measures will be required to mitigate the hazard.

4.2. Demolish and re-build school

At the other end of the spectrum from managed non-treatment as detailed in Section 4.2, the complete demolition and of the existing school building would allow unhindered access to the area requiring stabilisation, enabling access for drilling rigs to undertake all treatment points via vertical boreholes and negating all issues associated with inclined drilling as well as other access constraints. Following treatment of mineworkings the site would be suitable for the construction of a replacement school building.

However, due to a combination of cost, logistics and potential disruption to the staff and pupils, this is not currently understood to be desirable solution.

4.3. Engineered Solution

The use of geosynthetics such as geogrids/fabrics or hard engineering such as concrete slabs (piled or otherwise) can be used in certain circumstances to “bridge” old mine workings and provide protection to the ground surface. Such solutions do not eliminate the stability risks posed by underground workings and are most frequently used in situations where the risk is judged to be marginal, often being employed for non-structural linear developments such as roads or railways, or for car parks.

The presence of the existing school building, together with the fact that the underlying workings at the site are at particularly shallow depths with large residual void spaces, rules out the feasibility of using engineered solutions to mitigate the stability risk.

4.4. Drill and grout partial footprint

Due to the difficulties associated with drilling and grouting such shallow workings beneath the existing school building, as detailed in Section 3 above, consideration has been given to the viability of undertaking drilling and grouting beneath and around the outer parts of the school, omitting the central part of the building footprint where the extreme angles required renders conventional drilling techniques impractical. This would be intended to provide “betterment” to the situation, stabilising the outer load-bearing walls of the structure and likely preventing damage to the external parts of the school building.

However, reference to the available floor plan drawings of the school building suggests that internal walls surrounding the central school hall are also load bearing and would remain unsupported following the partial grouting treatment proposed, together with the central floor of the building which may be adversely affected by the formation of crown holes in the future. Moreover, a partial treatment solution would be an unsatisfactory outcome for all parties since guarantees could not be provided as to the complete remediation of the mining instability problem, and Fife Council would remain liable for any future damage sustained to the building, having indemnified the Coal Authority against their liability under the Coal Mining Subsidence Act 1991 under the terms of the Coal Authority Permit system.

4.5. Drill and grout entire footprint

Having assessed the possible solutions to the mineral instability problem at the site of Lochgelly South Primary School, with reference to the relevant CIRIA guidance on the subject (Ref.1), we have concluded that the most robust, safe, economical and practical solution is to undertake consolidation by drilling and grouting beneath and around the entire footprint of the school, including the central part where access by conventional means has been identified as problematic.

In order to achieve this, drilling and grouting via conventional vertical and inclined boreholes would be undertaken from outwith the school building as detailed in 4.4 above. Additionally, consolidation by drilling and grouting would require to be undertaken from within the existing school building where external inclined holes are unable access. Detailed proposals for this aspect of the works are yet to be formulated but it is anticipated that significant enabling works, specialist plant/techniques, and reinstatement would be required, including, but not limited to:

- Detailed structural surveys of the school building
- Surveys for buried services, drainage and foundations
- Removal of some internal fittings at school entrances to allow safe access for plant
- Removal of internal furniture, fittings and fixtures
- Sealing of classrooms and protection of walls of assembly hall
- Use of small drilling rigs with cut-down masts
- Use of electric rigs with remote power packs located externally to the school building
- Robust temporary ventilation system
- Sufficient lighting
- Continuous monitoring of structural integrity of building during the works
- Extensive cleaning of school interior upon completion
- Reinstatement of flooring and external walls

The exterior and interior elements of the consolidation works could be carried out in two separate phases or under a single mobilisation but would require detailed design works, careful planning and extensive controls as detailed below.

5. Controls Required for Drilling and Grouting Works

5.1. Health and Safety

Over and above the typical risks that are applicable to works of this type which a competent specialist contractor would be expected to address as part of their methodology and risk assessment process, the following specific health and safety considerations have been identified:

Mine gas

Investigations have been carried out to establish whether there are currently any elevated levels of mine gas within the workings at the school site. These investigations comprised the installation of gas and groundwater monitoring wells within boreholes sunk to the level of both sets of workings and an ongoing regime of gas monitoring over the weeks and months following installation. Refer to appended Drawing No. 148535/9003 for the locations of gas monitoring boreholes.

The results of the gas monitoring investigations have indicated that the risk of mine gas generation is low, with steady state CO_2 readings being recorded at low levels in both sets of workings, together with negligible levels of CO and H_2S. Additionally, borehole water level readings suggest that the workings in the lower of the two coal seams, the Lochgelly Parrot Coal, may be filled with groundwater which would prevent the accumulation of mine gas therein.

Nevertheless, as is standard with all consolidation of mine workings by drilling and grouting, a monitoring regime will be undertaken during the works to maintain a check for any elevated levels of mine gas. This will comprise daily gas monitoring of selected treatment boreholes during the drilling and grouting works, together with the use of precautionary gas alarms installed within the school building if any staff or contractors require access.

All drilling works will also require to be undertaken using water as the flushing medium as opposed to compressed air since the former technique is known to causes less mobilisation of mine gas.

Upon completion of the mining consolidation works the risks from mine gas accumulation are effectively negated by the infilling of the old workings and the reinstatement of the playground and school floor surface.

Safety in relation to angled drilling

Despite the use of angled drilling at > 45^{o} from the vertical being ruled out (refer to Section 3), inclined holes up to 45^{O} still have inherent difficulties compared to vertical or near vertical boreholes. Handling and placement of drill casings and rods onto the drillstring at such angles is hazardous from a manual handling perspective while other hazards include such as working at height due to the potential requirement to stand on the drill table to fit the rods and casings, and impact caused by the potential for safety cage doors to swing open suddenly.

The Contractor will be required to detail their measures to mitigate the risks of angled drilling within a robust Risk Assessment and Method Statement, and controls will be required on site to ensure that mitigation measures are being followed and are effective.

Access and traffic management

The site is situated in a residential area and has a narrow entrance and route past the school building to the rear of the playground. Frequent daily deliveries of plant and grouting materials will be required during the course of the works and careful planning will be required to ensure the safety of pedestrians, vehicles and other road users. The contractor will be required to details their measures to mitigate the risks from plant and vehicle movements to and from, and within the site, in a detailed traffic management plan.

Measures will also be required to maintain the cleanliness of the public roads surrounding the school, including, but not limited to, the use of wheel washing and road brushes.

Works within enclosed space

Special measures in relation to ventilation during works within the school building will be required. Electric drilling rigs with remote power packs are available which would prevent the build-up of exhaust fumes within the building. Alternatively temporary ventilation systems can be designed to continuously vent the atmosphere and thus protect the workforce.

A robust evacuation plan requires to be formulated and communicated to the workforce in the event of an emergency within the school building during the works.

5.2. Environmental

As with all drilling and grouting projects, measures to control the environmental impact of the works will require to be put in place, these being of particular importance given the sensitive location of the site in a residential area. The contractor will be required to detail and implement measures to mitigate the following hazards:

Water and grout runoff

The water from drilling operations and any grout spillage will require to be kept within the site boundary and prevented from entering into the drainage system or any watercourses. Runoff may be controlled by the use of trenches or sumps and/or sandbags whilst recirculation of flush water via specialist pumps may be utilised. Any waste water will require to be removed from site and disposed of via a licenced waste carrier. Build-up of water/grout spillage during the internal works will require particular control to prevent undue damage to the school infrastructure.

Spillage of fuel/oil

Measures to minimise the risk of spillage during refuelling operations will require to be detailed and an action plan will require to be in place to deal with the spillage of oil or fuel on site. Spill kits will be required on site with operatives trained in their proper use. Used spill kits will be disposed of as special waste via a licensed waste carrier.

Dust

The drilling process is unlikely to produce any significant dust since water will be specified as the flushing medium instead of compressed air. However, the process of mixing grout and storing grout materials can produce airborne dust if not managed effectively.

The grout utilised will comprised a mixture of cement, pulverised fuel ash (PFA) and sand. Cement is likely to be delivered in 25kg bags which will minimise airborne dust production when stored correctly. However, PFA is likely to be delivered in 20 tonne bulk loads and stored loose on site. The PFA will require to be watered down regularly during mixing and covered when not in use. The PFA storage area should also be located as far as reasonably practicable from any residential properties.

Mixing of grout is also liable to produce airborne dust since the mixer is typically loaded by the bucket of a telehandler or similar and cement/PFA dust becomes airborne when the material is dropped from the bucket into the hopper. Measures to minimise airborne dust from this process include watering down during loading, bespoke hatches covering the hopper, and dust screens erected around the mixer. The mixing plant should also be situated as far as reasonably practicable from neighbouring properties or other potential receptors. Mixing and handling of dry grout materials should not be carried out within the school building.

The Contractor will be required to detail their measures to limit the production of airborne dust to mitigate the hazard to the workforce, members of the public and property.

<u>Noise</u>

Significant noise levels are generated from the operations, particularly with respect to the rotary percussive drilling rigs which are typically used. Depending on the specific rig type, Noise levels of 95dB can be produced at a distance of up to 11.5 metres from the source while levels of 85dB have been recorded up to 24.3 metres from the source (ref. 5).

Noise is also produced from the operation of the grout mixer and ancillary plant such as telehandlers, water pumps and generators, albeit generally to a lesser degree than drilling rigs.

Little can be done to reduce the noise levels produced from drilling and grouting operations and therefore the works should be planned only to take place during standard daytime hours to minimise disturbance to neighbours and members of the public. Operators of the machinery, other site staff and visitors to the site will require to use hearing protection when in proximity to working plant, and appropriate warning signs should be erected.

Silenced generators and water pumps etc. will be required and the grouting plant should be set up as far as reasonably practicable from neighbouring properties.

<u>Vibration</u>

While significant vibration levels are produced during drilling operations due to the percussive nature of the drilling techniques, the majority of this vibration is directed in a downward direction as the drill bit progresses down through the path of the hole. The lateral component of vibration is variable depending on the nature of the strata being penetrated; in general terms less vibration is produced within soils than in rock, and harder bands of rock such as sandstone will generate more vibration than softer types such as shale.

Nevertheless, rotary percussive drilling is frequently undertaken in proximity to structures such as retaining walls or existing buildings, and we would consider that this technique is appropriate for the environment in which these works are proposed. A programme of continuous vibration monitoring at the school building and at the site boundaries would be advisable during the course of the works to allow a record of vibration levels to be kept and to alert in the event of any raised vibration levels.

5.3. Quality

Given the complex nature of the consolidation works, strict controls on quality management will be required to ensure that the works are carried out in an efficient manner and that accuracy is achieved with both the drilling operations and the placement of grout.

Clear lines of communication are required between the Engineer and the Contractor to ensure that unambiguous instructions are issued in relation to such matters as hole locations, drilling angles, re-drills, effective grout placement and formation of an effective perimeter to prevent excessive grout loss in a down-dip direction outwith the footprint to be consolidated.

The contractor will be required to employ an experienced supervising engineer and site foreman to maintain the required level of site control, and will also be required to detail their proposals for quality management in line with a robust specification for the works.

6. References

1. CIRIA C758D Abandoned Mine Workings Manual, 2019
2. Soil Engineering Geoservices Ltd: Noise Level Readings for Soilmec SM14 and Boart Longyear DB420 rotary percussive drilling rigs, received 25/04/2022.

Appendix

Drawing No. 148535/9003 – Composite Site Plan Including Investigation Borehole Locations