Historical Chalk Mines Below Pinner Wood School

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ABSTRACT The unknown location of old historic chalk mines, shafts and adits beneath the streets, properties and structures of London present serious issues for the local communities. A major concern for these communities is that collapses of these workings could occur at any time and without any prior warning. When they do occur those who are affected want to know the full extent of the problem, is it localised or extensive?

This paper examines the ground investigations and surveys of historical chalk mine workings beneath a community primary school in Pinner, Middlesex and the specific use and analysis of subsurface laser scanners to identify the precise location and extent of the previously unknown and unmapped workings.

Following a ground surface collapse in 2015, intrusive ground investigations identified the presence of a loosely backfilled chalk mine shaft, extending to some 24m below ground level (bgl). Further investigations included the use of dynamic probes, window sample boreholes, hollow stem auger boreholes. Rotary boreholes, with measurement of penetration rate, percentage flush return, applied load on the drill head and rotary speed, were used to provider greater clarity regarding the ground conditions. These intrusive works were supported by site wide geophysical investigations, utilizing Ground Penetrating Radar (GPR) and Electromagnetic (EM) mapping.

Specialist Geospatial Engineers, Geoterra deployed their geo-referenced Cavity Auto Scanning Laser System (C-ALS) to carry out multiple subsurface void laser scan surveys and then data processed using bespoke Cavity Profiler software.

The use of subsurface laser scanning has enabled large sections of open mine workings to be quickly and accurately mapped, in three dimensions, saving significant time and cost in the process of mapping the extent of the former chalk mine workings. Laser scanning also reduced the health and safety risks associated with intrusive investigation methodologies as well as being far more sustainable, compared to the use of heavy plant and associated materials required for intrusive investigation.

Analysis of the further ground investigation and survey data by Peter Brett Associates has enabled informative decisions to be made with regards to effective remediation solutions and mitigation measures.

1 BACKGROUND

Pinner Wood School is a primary school located to the northwest of London, some 3.5km northwest of Harrow. The school is under the administration of the People's Capital Team at Harrow Council, the client.

In August 2015 a shallow ground collapse occurred suddenly (a small hole quickly expanded to approximately 3m in diameter and 2m in depth) within the car park near the south east corner of the site and immediately in front of the school's main entrance. The school was in use at the time of the collapse but thanks to observant responsive staff no one was injured in the event. The void was quickly backfilled with aggregate and the area fenced off. Structural surveys carried out at this time did not identify any associated building damage, however, a program of ongoing visual monitoring was established.

Despite significant background research, including searches of commercially available cavities databases, website searches, discussions with local historians and other parties with local knowledge, no site specific maps or written records could be found indicating the location of pits, shafts or historical chalk mine tunnels within the site boundary. Only one piece of evidence emerged during searches, a Tithe Map identifying the site and immediate surrounds as 'Chalk Pits Field'.

Whilst no information could be found regarding historical chalk mining below the site itself, there are extensive records of chalk mining in the wider area (Gallois 1982 & Kirkman 1992). The mined chalk was used for a variety of purposes, such as in brick, tile and pottery making. The geological unit mined below the site is the Seaford and Newhaven Chalk Formation, at around 20m-25m bgl (BGS 2006), with groundwater estimated at around 40m bgl (BGS 1984).

2 PRELIMINARY STUDIES

Initial investigation works in September 2015 were aimed at trying to determine the underlying cause of the collapse, most likely induced by water inundation. These investigations included dynamic probe holes immediately surrounding the collapse and a single probe hole through the centre of the collapse. The probe through the centre of the collapse indicated very weak ground to some 26m bgl, whilst the surrounding probe holes all terminated at shallow depth in ground interpreted as undisturbed. This information, together with knowledge of chalk mine workings present in the wider area, suggested the feature may be an old mine shaft, or possible exploratory shaft.

Due to the ongoing use of the school, investigations were restricted to localized areas, or carried out during holiday periods, resulting in an extended period of investigation and assessment.

The next phase of works comprised geophysical surveys, carried out across the entire school site, in October 2015. The survey methods used picked up multiple discrete isolated Ground Penetrating Radar (GPR) anomalies, a number of discrete Electromagnetic (EM) anomalies and a series of locations where both the GPR and EM anomalies coincided.

A subsequent intrusive ground investigation was carried out, in August 2016, concentrating on the anomalies identified by the geophysical survey. Whilst most of these anomalies did not prove any significant depth of soft/disturbed ground, there was a deeper anomalous feature directly to the south of the school building. This anomaly was found to comprise a significant depth of made ground with very weak ground extending to some 22.5m bgl.

Further to completion of the geophysical survey and ground investigations around the site, ground treatment works began in November 2017 and ended in February 2017. The first treatment area (Main Shaft) was centered on the original collapse. The second treatment area (Southern Shaft) was located to the south side of the site.

During this phase of the works it became apparent that the grout takes were significantly greater than originally anticipated. It had been thought that the shafts could be treated in isolation, however, the grouting work demonstrated that there were, potentially inter-connected open chalk mine workings. A second round of boreholes were drilled both at the Main Shaft and the Southern Shaft, in March 2017, further from the central location of the shafts. Voids were encountered in some of these boreholes and laser scan surveys were carried out.

The results of this work showed there was a substantial tunnel network underneath the southeastern corner of the school building. Within this tunnel network there was evidence that the roof of some parts of the tunnels has collapsed. At this point, given the risk to the overlying building and its users, Harrow Council (People's Capital Team) took the decision to close the site. Although it was understood that the possibility of a sudden and substantial collapse was low, based on available information, the consequence of such a collapse endangering staff and pupils was considered to be unacceptably high.

Following the closure, more extensive intrusive investigations could be carried out, that encompassed the whole site, without the health and safety risk associated with an operating primary school. This investigation was completed in June 2017. Where voids were encountered further laser scan surveys were carried out. The results of these additional works and laser scan surveys showed extensive, open chalk mine workings.

A phased approach was recommended for remedial stabilisation treatment. Where open mine workings were encountered, they were bulk infilled with a high viscosity cement grout mix. A pfa, cement grout mix at a ratio of 10:1 was adopted for this phase of the treatment works. Following the infilling work a second phase of compaction grouting works were carried out in areas of ground above and around former open voids or where significant depth of soft/disturbed ground was encountered during the ground investigations. This process involves pumping a stiffer cement grout mix, under pressure, into the ground, from competent chalk at depth, to near ground surface. A sand, cement, pfa, bentonite mix in the ration of 6:2:1:0.1 was adopted for this phase of the treatment works. This method serves to infill any small residual voids encountered and compact the surrounding soft/disturbed ground, thereby increasing its strength and mitigating the potential for future ground movement to occur.

A key objective for the ground stabilisation work was to complete the treatment below and around the school buildings by the end of December 2017, to enable reoccupation of the school building in January 2018.

This case study demonstrates the value of multiple lines of evidence approach to ground investigation and the benefits of utilizing innovations in investigative technology.

3 SITE WIDE GROUND INVESTIGATION

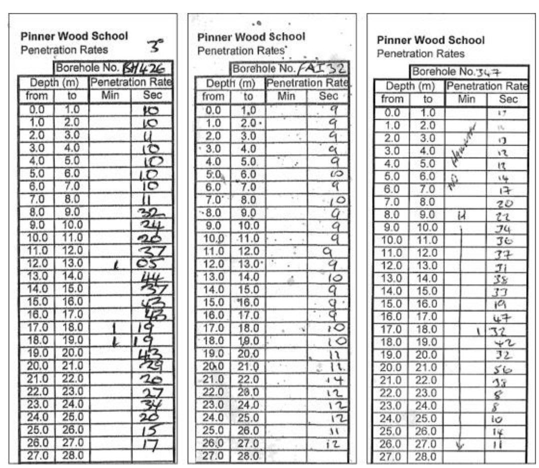
3.1 Investigation Strategy

Following the initial phase of grouting, further investigations and laser scan surveys and assessment of the potential risks to the users of the school facilities, a decision was taken to temporarily close the school to enable site wide ground investigations to be carried out.

Boreholes were proposed at locations across the site to cover all open areas, on a 5m offset grid spacing. The grid spacing was chosen due to the potential width of mine tunnels, being around 3m, so that with the offset spacing there would be a high probability of locating any former chalk mine workings. In addition, a series of close centered boreholes were located around the outer perimeter of the buildings. These boreholes were set out on a 1.5m spacing.

At the end of this phase of investigation some 800 boreholes were completed, using rotary probing drilling methods. The manner of drilling was kept constant (rotary speed and applied load) to ensure consistency in the penetration rate readings. Refer to Figure 1. The drillers recorded the time it took for each meter to be drilled. This data was used, together with the drillers' logs to assess the ground profile of each borehole location.

Three typical logs have been reproduced in Figure 1. Probe BH426 indicates an undisturbed ground profile. Whilst the near surface materials are weak, this is attributed to historical near ground surface disturbance. Penetration rates are shown to slow significantly below 8m depth, with chalk encountered at 22m depth. By contrast probe FAI32 shows a disturbed ground profile over the full depth of the log, with penetration rates remaining rapid through the top of the chalk at 22m and to termination depth. This log is interpreted to represent a highly disturbed ground profile resulting from the collapse of underlying chalk mine workings. Probe BH347 has an undisturbed ground profile to 22m depth, where penetration rates rapidly increase. This log is interpreted to represent relatively undisturbed ground over intact chalk mine workings, with open void space between 22m and 24m depth.



Pinner Wood School
Penetration Rates 3

Borehole No. BH426

Depth (m) from	to	Penetration Rate Min	Sec
0.0	1.0		10
1.0	2.0		10
2.0	3.0		11
3.0	4.0		10
4.0	5.0		10
5.0	6.0		10
6.0	7.0		10
7.0	8.0		11
8.0	9.0		32
9.0	10.0		24
10.0	11.0		20
11.0	12.0		37
12.0	13.0	1	05
13.0	14.0		44
14.0	15.0		37
15.0	16.0		43
16.0	17.0		48
17.0	18.0	1	19
18.0	19.0	1	19
19.0	20.0		43
20.0	21.0		29
21.0	22.0		20
22.0	23.0		27
23.0	24.0		34
24.0	25.0		20
25.0	26.0		15
26.0	27.0		17
27.0	28.0		

Pinner Wood School
Penetration Rates

Borehole No. FAI32

Depth (m) from	to	Penetration Rate Min	Sec
0.0	1.0		9
1.0	2.0		9
2.0	3.0		9
3.0	4.0		9
4.0	5.0		9
5.0	6.0		10
6.0	7.0		9
7.0	8.0		10
8.0	9.0		9
9.0	10.0		9
10.0	11.0		9
11.0	12.0		9
12.0	13.0		9
13.0	14.0		10
14.0	15.0		9
15.0	16.0		9
16.0	17.0		9
17.0	18.0		10
18.0	19.0		10
19.0	20.0		11
20.0	21.0		11
21.0	22.0		14
22.0	23.0		12
23.0	24.0		12
24.0	25.0		12
25.0	26.0		11
26.0	27.0		12
27.0	28.0		

Pinner Wood School
Penetration Rates

Borehole No. 347

Depth (m) from	to	Penetration Rate Min	Sec
0.0	1.0		17
1.0	2.0		[illegible]
2.0	3.0		13
3.0	4.0		12
4.0	5.0		13
5.0	6.0		14
6.0	7.0		17
7.0	8.0		20
8.0	9.0	[illegible]	22
9.0	10.0		24
10.0	11.0		36
11.0	12.0		37
12.0	13.0		31
13.0	14.0		38
14.0	15.0		37
15.0	16.0		19
16.0	17.0		47
17.0	18.0	1	32
18.0	19.0		42
19.0	20.0		32
20.0	21.0		56
21.0	22.0		38
22.0	23.0		8
23.0	24.0		8
24.0	25.0		10
25.0	26.0		14
26.0	27.0		11
27.0	28.0		

Figure 1. Penetration rate logs

3.2 *Results of Investigation*

The borehole data was analyzed as the information was provided and a series of updated interpretive plans were produced on a regular basis as the works progressed. Refer to Figure 3 (MS is the Main Shaft and SS is the Southern Shaft). The plans presented are colour coded to show three broad classifications of ground conditions as below:

- Red – where voided or broken ground was encountered, associated with historical mining
- Yellow – where soft/disturbed ground was encountered, possibly associated with historical mining
- Green – undisturbed ground with no evidence of disturbance from historical mining

Where voided locations were encountered, plastic casing was installed in the boreholes to the top of the voids to prevent any ground collapse so that down hole High Definition Close Circuit Television (HD CCTV) camera and laser scan surveys could be carried out.

Figure 2. HD CCTV camera void surveys set up

HD CCTV camera surveys were subsequently carried out in 23 of these boreholes and C-ALS, laser surveys carried out in 34 boreholes.

Figure 3. Interpretive plan

4 LASER SCAN SURVEYS

Specialist geospatial engineering surveyors were brought onto the project in March 2017, when it became apparent that the voids were larger than had been originally anticipated and geo-referenced void laser scan surveys were required.

4.1 *Phase One*

Four voids had been originally encountered within the ten boreholes around the east and south side of the school. The Cavity Auto Scanning Laser System (C-ALS) was deployed down each of the boreholes and full geo-referenced 3D laser scans were carried out on the four voids. Co-ordination of the borehole and the boretrack rods to Ordnance Survey Great Britain (OSGB) National grid and Newlyn Global Positioning System (GPS) level datum provided the baseline from which the void laser scan deployment down each borehole could be tracked until the laser scan head reached its optimum position, the approximate centre of the void, approximately 28m bgl. HD CCTV camera surveys were also carried out in each of the same voids.

A surface laser scan survey of the external school building was carried out using a FARO Focus laser scanner and a full colour 3D point cloud produced on which to provide a platform to combine with the subsurface void laser scan surveys.

Figure 4. C-ALS survey surface installation set up

The four laser scan surveys were processed in Renishaw bespoke cavity profiler software to provide a full 3D void point cloud. The combined 3D model deliverable point cloud was produced in Navisworks .RCS and .RCP format to be viewed in Navisworks Freedom software.

The distinct advantage of having the surface buildings and subsurface voids laser scans combined into a single geo-referenced model quickly became apparent when the location of the phase one void surveys were analysed within the interactive 3D model. Not only were the voids larger than had been anticipated, they were actually beneath the school buildings and appeared to extend even further in several directions than previously identified.

The C-ALS is only able to survey from the position within the void dictated by the location of each borehole i.e. it can only move up and down to the optimum position vertically to achieve the maximum 3D scan of the chalk mine workings.

From the initial phase one scans it was clear to see that the chalk mine workings were typical bord and pillar. The C-ALS scanned a large portion of the workings and part of workings until they disappeared out of the line of sight of the scanner. The combined surface and subsurface voids was then analysed in the 3D interactive model in detail and used in subsequent discussions with the Council to visually determine what actions were to be taken.

4.2 Phase Two

Following analysis of phase one void surveys additional boreholes were drilled around the school, both in the playground and in the playing fields. An additional 30 voids were encountered.

Further C-ALS surveys of each of the voids were carried out and all of the void point cloud data together with the surface point cloud data was combined into a single 3D geo-referenced model for interpretation by the Engineer. Additional HD CCTV camera surveys were also carried out in most of the same voids.

Figure 5. Navisworks point cloud model isometric

Figure 6. Navisworks point cloud model plan

5 GROUND STABILISATION WORKS

5.1 General

Based on the results of the site wide investigation, further ground stabilisation works were carried out in several areas of the site. This work was carried out by a combination of bulk infilling of open void space and compaction grouting of disturbed weak ground overlying the historical chalk mine workings. The latter is interpreted as having been caused by the progressive breakdown and relaxation of the ground over the mine workings as they have degraded with time.

5.2 Remedial Stabilisation Strategy

Firstly, bulk infilling of open mine tunnels, detected by downhole laser scanning and HD CCTV surveys, was carried out, prioritising the infilling of voids below the school buildings. Secondly, compaction grouting was carried. Compaction grout holes were set out on a 3m grid with a typical treatment depth of up to 24m bgl, locally adjusted based on the results of the completed ground investigations.

Since not all areas of ground that might contain old chalk mine workings were investigated, below the school footprint, the compaction grouting works extended from areas of known disturbed, mined ground around the school buildings towards and under the adjacent areas of the school buildings where the ground conditions were unknown but where chalk mine workings were strongly suspected.

On completion of the ground stabilization works, some 3,400 tonnes (approximately 2,200m^3) of grout had been injected into open voids across the site, with a further approximately 1,500 tonnes (approximately 950m^3) of grout injected through compaction grouting techniques in areas of significant ground disturbance. Some 500 boreholes were drilled to facilitate this treatment work.

6 CONCLUSIONS

Following a ground surface collapse in the summer of 2015 a series of intrusive and non-intrusive ground investigations and stabilization works, were carried out in several different areas of the site. These were initially carried out during periods when the site was occupied or during school holidays and as a result they took an extended period of time to complete.

Early in 2017, the site was temporarily evacuated and site wide ground investigations began. Adopting rotary probing drilling methods for the bulk of these investigations enabled a large number of investigation holes to be completed very quickly, with the ground conditions being interpreted as the works progressed.

The use of down hole laser scan surveys significantly reduced the number of investigation boreholes required and provided 3D models of void space encountered. Large areas, particularly those difficult to reach, below buildings did not need intrusive investigation, saving the Client significant cost and time.

This information fed into the design process for ground stabilisation works, which began in June 2017 and completing in January 2018. The 3D analysis enabled targeted bulk infilling works to be carried out and greatly improved the ability to accurately cost and programme these works. The school was reopened and reoccupied on schedule for the start of the new term.

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