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LESSONS FROM OVERCOMING GEOTECHNICAL PROBLEMS ON BROWNFIELD SITES

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This work considers the regeneration of an extensive group of brownfield sites concentrating on the period 1975-81 but including material up to 2009. Previously used for collieries, heavy industry, and spoil disposal, with low lying areas subject to flooding, the sites posed problems in the superficial deposits as well as from disused mine workings. Crucial lessons are the importance of enabling clients to understand the issues that they face; researching, identifying and resolving problems; and the risks, costs and timescales involved. These lead to the requirement to keep abreast of new developments and techniques for ground investigation and treatment so that we are able to consider the best options. Thorough research, investigation and testing were also essential. For success there needs to be the political and financial will to enable long term development to suit society's changing needs and ensure sustainable economic development.

INTRODUCTION

This paper considers the lessons to be learned from the long term development of a complex brownfield site. It must be stated at the outset that a single paper cannot do justice to the full extent of the work carried out in regenerating the Cambuslang Redevelopment Area on the south-eastern edge of Glasgow on the banks of the River Clyde and west of A763. Although the work began in 1975-6 there was exploratory work in the area at least as early as 1973, and much of the development was carried out after 1981 when the author left the Scottish Development Agency, and subsequently after the SDA and its successor, Scottish Enterprise, had begun disposing of the land and properties.

It is clear from this that the redevelopment of major industrial sites may take many years, especially when, as in Cambuslang, there has been heavy industrial use, mining, and associated waste.

To provide as full a picture as possible, this Paper considers the solid and drift geology of the site, the industrial and other uses of the site, the resulting problems, options for solving them, and the results. Given that geography, geology and land use are related, it is first helpful to understand something of the history of the site.

HISTORY

The area under consideration has been used for industry for over 200 years, and perhaps from as early as 1500.

In Figure 1, a map from 1795, the location of Clyde Iron Works is clearly marked, as are 'Bogleshole' which was the name of a road on the site, some buildings which may have been associated with coal workings, Hamilton Farm, and the River Clyde.

The River is not especially wide here, - maps show two fords - except when it rises as a result of heavy rainfall in the hills in Lanarkshire, when a change of level of 6 metres overnight can cause local flooding, as witnessed by the author in 1977 or 1978. This posed potential problems which also required consideration.

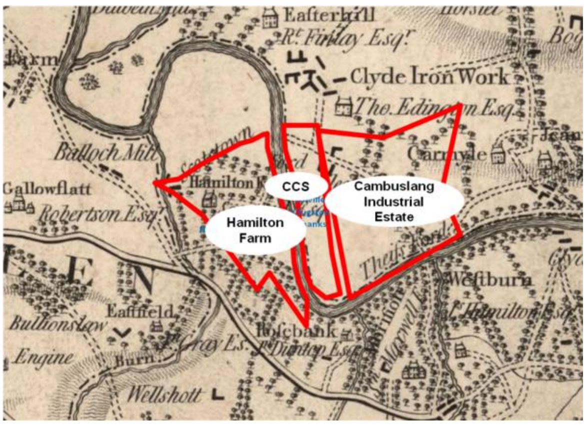

Figure 1: Maps of Cambuslang 1795 – 1934, (1795), showing SDA's initial three site boundaries

A map of 1962 or later reveals the area to have been developed as shown in Figure 2. with an extensive area for the Clyde Iron Works, and, linked by rail, associated slag works. There are also brickworks, but the former collieries are no longer shown.

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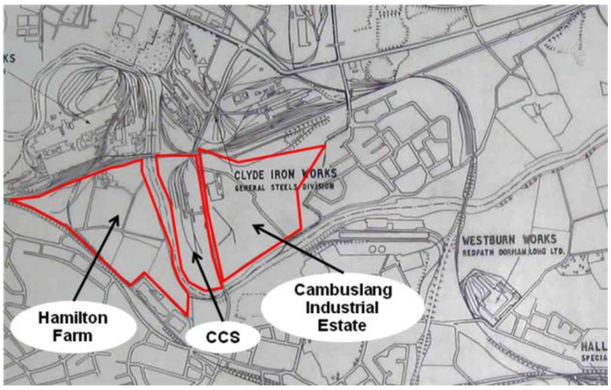

Figure 2: Maps of Cambuslang, 1795 – 1934: 1962 or later, showing SDA's three initial site boundaries

Figure 3 (Scottish Enterprise records) shows the Clyde Iron Works immediately north of Cambuslang Industrial Estate after 1980.

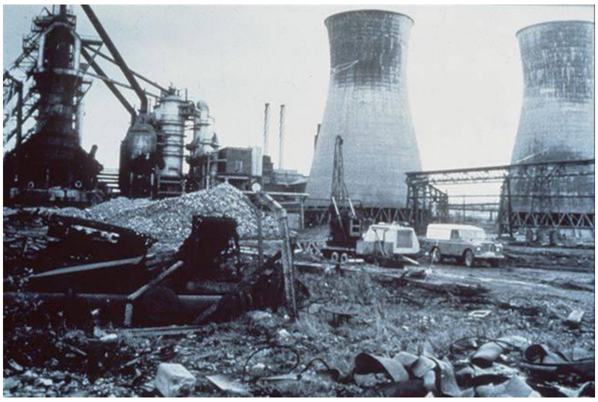

Figure 3: Clyde Iron Works, from Scottish Enterprise records after 1980

By 1973 with the closure of the steelworks foreseeable, and the colliery and associated brickworks already gone, there was an economic imperative for new industry.

Cambuslang Redevelopment Area

In 1975 the Scottish Development Agency took over responsibility for the redevelopment of a 30 hectare derelict site in Cambuslang on the south-eastern edge of Glasgow. This was a major brownfield site at a time when the term was hardly used.

The developments were subsequently expanded to encompass more of the local area both sides of the River Clyde, and a total area of over 100 hectares. This paper is most concerned with Cambuslang Industrial Estate, but there are references to other areas, notably Colvilles Clugston Shanks (CCS) and Hamilton Farm, as shown in Figure 4.

The area of the first phase of Cambuslang Redevelopment is shown in Figure 4, which reveals more clearly the colliery works, but the location of the associated pit shafts and extent of the workings are not clear.

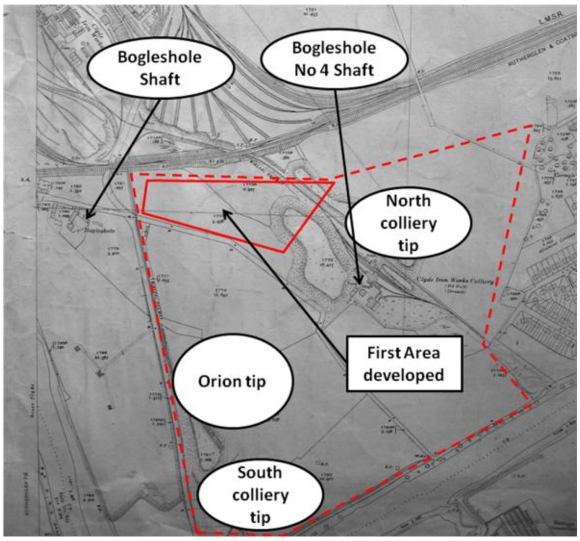

Figure 4: Maps of Cambuslang, 1795 – 1934: (1934) Extract, showing colliery features and Cambuslang Industrial Estate boundary.

GEOLOGY

From desk research the drift and solid geology was expected to be broadly as in Table 1.

Problems arise in the superficial deposits as well as in the solid strata.

Considering firstly the solid which provides important constraints on the areas that would be agreed initially as suitable for development, of greatest interest in this context is the depth and extent of mineral workings.

Limestone Coal Group

The coal-bearing strata are described in BGS British Regional Geology The Midland Valley of Scotland (1985) as follows:

> *"The Limestone Coal Group varies greatly in its development from a thin sandy sequence about 30m thick with thin coals in parts of Ayrshire, up to 550m in the northern part of the Central Coalfield, where there are about 15 workable coal seams"*

Relating this general description directly to the site in questions, the Geological Survey of Scotland (1926) chart recorded for Bogleshole Pit No 4 reveals workable seams at various depths, reaching about 200m below ground level.

Table 1 Stratigraphy

<table>
<tr><td colspan="3">Fill or made ground over parts of the site
Note that for the purposes of the Paper no distinction is made between the terms “Fill” and “Made Ground” as it is not clear that a genuine distinction was made consistently in all of the reports and references which have been used. A paper by Rosenbaum et al (2003) provides classifications that were not current at the time of the original developments.</td></tr>
<tr><td colspan="3">Sandy Clays, silty clays, silts and sands
Sand and gravel
Laminated silty clays and silts
Sandy clays with gravel, cobbles and boulders</td></tr>
<tr><td rowspan="6">Upper Carboniferous</td><td rowspan="3">Coal Measures</td><td>Upper Coal Measures</td></tr>
<tr><td>Middle Coal Measures</td></tr>
<tr><td>Lower Coal Measures</td></tr>
<tr><td rowspan="3">Millstone Grit Series</td><td>Passage Group</td></tr>
<tr><td>Upper Limestone Group</td></tr>
<tr><td>Limestone Coal Group</td></tr>
<tr><td>Lower Carboniferous</td><td>Carboniferous Limestone Series</td><td>Lower Limestone Group</td></tr>
</table>

Adapted from ground investigations and BGS British Regional Geology (1985) Permission of the British Geological Survey

JWH Ross and Co, (1973, 76, 77, 79), retained as mining consultants by the Scottish Development Agency, provided many reports over the years major aspects being:

- The location of disused pit shafts. While the existence of some might have been indicated by depressions in the ground, the exact location of them would require careful investigation;
- The extent of mineral workings;
- The type of workings, generally believed to be ‘stoop and room’, described below;
- The condition of these disused workings.

The problems therefore included dealing with the result of disused and poorly recorded coal workings, JWH Ross and Co establishing that they were ‘stoop and room’ (or termed ‘pillar and stall’ in England). Beneath Hamilton Farm there were six seams which had been mined: the Upper, Ell, Main, Humph, Splint and Kiltongue, to a depth of about 200m. For this, the technique is described by Bulmans and Redmayne (1925):

> *“Narrow places are first driven in the seam so as to form pillars, which are subsequently removed”*

Bulman and Redmayne, (1925), include a description of the same type of workings from a record dated 1828**:**

> *“On inspecting the workings I found they were pursuing the mode, almost universally practised in the district, of making the winning 9 yards, taking out or working as a bord 5 yards, and leaving unwrought or standing 4 yards as a pillar; afterwards 4/9ths of the coal is therefore lost. When the coal is drained by engine power, and when in working the pillars there is a risk in raising water, which by over-powering the engine might endanger the permanent safety of the colliery, it is often advisable to leave the pillars.”*

Summarising this, the process was to dig outwards from a shaft and create an expanding space, leaving columns of the existing rock in place to hold the roof up. This continued for some distance, basically until it was too far to travel from the shaft or there was some other impediment. Workings could take place at multiple depths if the coal seams were sufficiently thick as they were at Cambuslang.

When workings were due to cease pillars might be removed completely allowing the roof to collapse, but this was not universal.

If the shaft was filled afterwards, perhaps first cutting the cable to allow the lift to fall and jam, any fill material would not have been compacted. After closure ground water could fill the voids, and natural erosion would occur. Gas may also accumulate in any voids. Collapses of workings could then take place, resulting in unpredictable vertical and lateral ground movement above the workings, as well as at the disused shafts, with serious consequences. Bulmans and Redmayne (1925) state that:

> *“The damage caused to land and buildings by subsidence of the surface is a serious result of colliery working, which gives rise to much litigation, and is to many collieries a considerable item of cost.*
>
> *Decisions about it are based still on approximate rules drawn from varied*

experience rather than from scientific deduction.

The surface subsidence is not confined to the area of worked-out coal. There is a lateral as well as a vertical movement of the strata. The crucial question that usually arises for decision is the amount of "draw": how far over the solid unworked coal will the subsidence extend?"

They continue to report that the angle of draw might be from 5º – 15º in sandstone and shale, about 25º in the liassic rocks overlying the Cleveland limestone and in superficial formation such as boulder clay, it varies from 20º to 35º.

Bulman and Redmayne (1925) also noted that the depth of the surface subsidence is always less than the thickness of the bed removed:

"In a good many instances it appears to be about 60% of the thickness of the seam."

There being no available photographs from Cambuslang itself, as there was no access to the workings themselves, the scale of the potential workings and the general form that they took are illustrated in Figure 5, Geology of the Glasgow District, (1997) Plates 6a and 6b, which are of the same type of workings in the Glasgow area.

It is notable from this that voids could be many metres deep, the workings having been able to accommodate horse-drawn wagons for transporting coal, and they could occur at relatively shallow depth as can be seen. With possibly significant voids, even when these are at great depth, the potential for consolidation causing movement at the surface needs to be considered.

Mineral investigations together with available maps and other records enabled identification of the approximate extent of the works, and approximate location of two shafts. In the course of this work other shafts were also identified in the local area.

From these investigations, the approximate extent of disused mine workings and the problems they presented were clear, boreholes having revealed the likely presence of some voids. Part of the site was therefore left for possible later development, enabling design to concentrate initially on more suitable areas.

The actual shaft locations had to be confirmed by careful exploratory drilling, and then consolidated with cement grout.

We now consider the superficial deposits.

Permission of the British Geological Survey

Figure 5
From: Plates 6a and 6b from Geology of the Glasgow District
Top: Shallow workings showing Stoops and Rooms, Thornliebank, Glasgow
Bottom: Stoop and Room mining in the Bishopbriggs Limestone, Huntershill, Bishopbriggs, north Glasgow

<u>Drift geology</u>

The first detailed ground investigation revealed the strata at Cambuslang Industrial Estate to be as shown in Table 2, Scottish Enterprise, Soil and Mineral Reports, Wimpey Laboratories Limited (1976).

Summarising this, the ground was very variable, with extensive fill material much of which was waste from coal extraction, steel production and brickworks. The natural superficial deposits ranged from soft silts to gravel and boulders, with rock at 10 -27m below ground level.

Site investigation reports (Hydracrat, 1983, GKN Keller, 1977) on the neighbouring sites of CCS and Hamilton Farm reveal a similar picture, as illustrated in Figure 6. This is of CCS adapted from Swanson and Clow, (2008), (unpublished draft paper) who also refer to further ground investigations using static cone penetration tests.

Table 2 Summary of Ground Conditions

Fill	There were three tips: North Colliery Tip: predominantly colliery discard from 3m to 14m deep, and sand overlying it in parts South Colliery Tip: about 2.7m of colliery discard Orion Tip: more varied, including 7-8m colliery discard; large amounts of demolition rubble and industrial refuse; 7-12m of variable ash, stone, rubble, slag, brick, metal and timber.
Sandy clays, silty clays, silts and sands	Beneath fill where present, and elsewhere at the surface, sandy clays Thickness varied from 2.00 – 4.00m
Sand and gravel	Very consistent layer of medium dense sands and gravels, 2.00 – 6.00m thick
Laminated silty clays and silts	Deep deposits of soft laminated silty clays and silts, tending to be thicken in a westerly direction and thinnest or absent to the north east.
Sandy clays with gravel, cobbles and boulders	Very stiff brown and grey very sandy clay with gravel cobbles and boulders, with a maximum thickness of 11.75m at one borehole. It was thin becoming thicker to the south-west
Bedrock	Rockhead was predominantly sandstone, at depths from 10 – 27m. Some was weathered.

Wimpey Laboratories, 1976 (Adapted)

Summarising this for Cambuslang Industrial Estate, the first site to be developed, much of the ground was low lying and vulnerable to flooding requiring up to 4m fill to bring it to what was regarded, in 1976, as an acceptable level.

Accordingly prior to any development there needed to be significant earthworks to regrade the land above flood levels, requiring the import of some 500,000 cu.m of material.

The selected fill material was ‘black blaes’ brought in from West Lothian. With a loose density of about 1.4t/m3, rail was identified as a realistic option to minimise road haulage, and a rail heading was provided for materials to be brought in and off-loaded for distribution across the site.

We should therefore consider the nature of the chosen fill material.

Black Blaes

Blaes is waste oil shale, the residue after the extraction of mineral oil. Dr. Barbra Harvie (2005) describes the industry in West Lothian as follows:

> *“By 1865 there were 120 oil works in operation in the county, run by at least 20 different companies, with their associated shale pits and mines, producing more than 100 million litres of crude oil every year and employing 30-40,000 people. In 1866, Young's Paraffin Light and Mineral Oil Company Limited set up Addiewell works, the biggest oil works in the world.”*

By 1963 there were 27 bings containing over 200 million tonnes of burnt shale, and it was used extensively for roads including the M8 and M9 motorways.

The description also reveals that oil-shale waste has been heated to several hundred degrees centigrade before dumping. The substrate is (Harvie, p8)

> *“non toxic, containing none of the heavy metals or other toxins associated with industrial and mine waste. Oil-shale is alkaline, not acidic like coal spoil”.*

Localised Ground Conditions

The earthworks contract revealed another problem, which is where local research provided information. Weak compacted soils in one area of the site required a local change to the earthworks operations.

Discussions with a member of the public, an ex-miner, revealed the cause of this. He was able to identify fairly closely the locations of former buildings, their purposes, and the colliery’s lagoon. This area was lined with puddle clay, and, over the years, had been filled with colliery spoil and other materials. With water trapped by the clay, the fill material had become ‘running sand’.

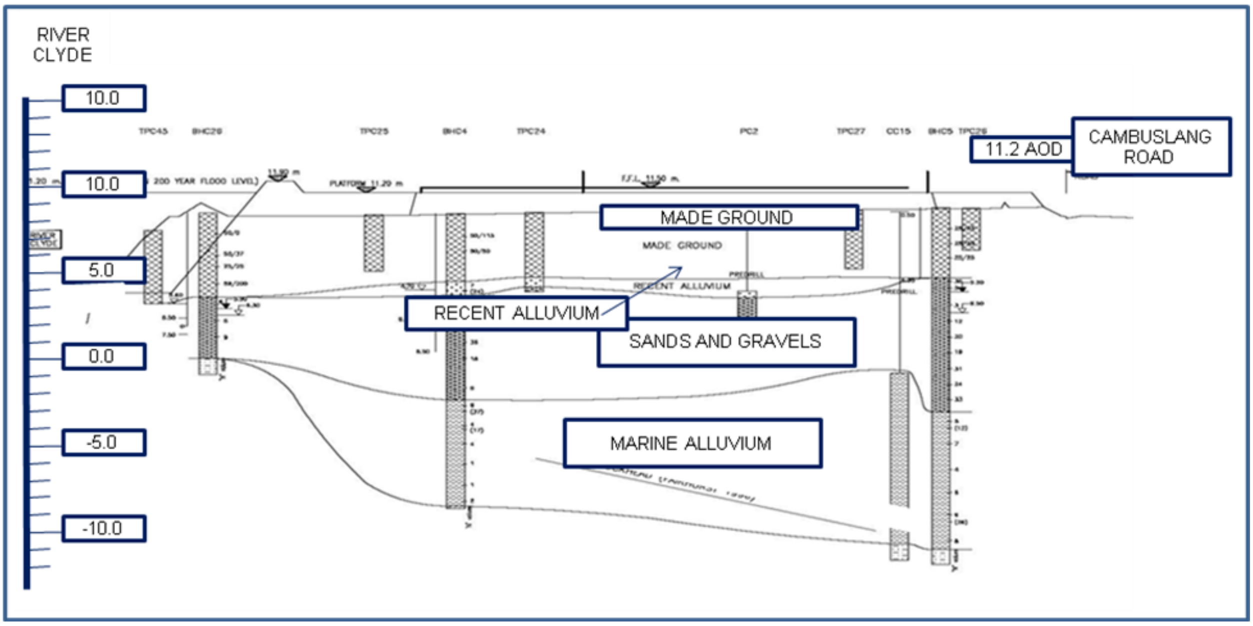

Figure 6 Adapted from Swanson and Clow, Cambuslang Investment Park - Construction on Clyde Alluvium Earthworks - Imported Fill (unpublished draft paper, 2008)

Summary of Ground Conditions

An area of the site was deemed unsuitable for early development, allowing design to focus on the remaining area and establish possible site layouts for new buildings, new roads and utilities.

Some material especially in the Orion Tip was identified as being contaminated and removed to a licensed site.

Disused mine shafts would need to be located and made safe.

Low-lying areas required to be filled, and potential further work to ensure suitability for subsequent development.

Other earthworks would be required to provide suitable formation levels for factory units, roads and services.

Ultimately, the overall site layout was agreed in general, enabling the location of the first four factory units to be determined, as shown earlier, in Figure 4, as the first area developed.

Overcoming the problems - Ground improvement

We now consider how best to ensure that the resulting site would be suitable for buildings. The fill which had been required to bring the ground to suitable levels for construction and drainage would not be sufficient immediately for building directly on, even when compacted using what were then standard methods: spread and roll in layers of not more than 150-250mms. This had achieved a density of around 1800kg/cu.m. routinely measured using specialist portable equipment, marked with the standard radiation sign. Radiation from the tip of a probe pushed into the ground provided immediate direct readings for the material's density. It was also subjected to other off-site tests.

Options

There were several options for ground improvement and foundations, detailed by Moseley (1993), and Xanthakos, et al, (1994):

1. Soil compaction and consolidation
2. In situ ground reinforcement
3. Vibro techniques
4. Vibro compaction
5. Vibro replacement process
6. Dynamic Compaction
7. Chemical grouting
8. Compaction grouting
9. Preloading
10. Piling

We should note that these references were unavailable at the time of the original works.

Selection of appropriate ground improvement technique is dependent on the structure to be built, the type, depth and variability of ground material, the depth of treatment required, and it may be influenced by both time and cost. Regardless of treatment, there is a need for monitoring, control and the verification of results.

Selection

The initial investigation suggested possible load bearing capacities ranging from 60kN/m^2 to 100kM/m^2, dependent on the actual location of eventual factory units, but, as was usual good practice and given the wide variations in ground conditions, it was essential for each unit to be considered individually. There were also recommendations that complete removal of the original colliery waste and other fill might be appropriate, and for this to be replaced with more competent material, or piles considered.

The preference was to begin construction as economically and quickly as possible. The buildings, steel-framed on a 7.2m grid with column loads of up to 45 tonnes, would have offices on one side, and a workshop floor load of 25kN/m^2 or more. These loads excluded any allowances for possible cranes.

Accordingly, when locations had been agreed, further ground investigations were undertaken for each unit. The focus was on ground improvement rather than piling, and vibro consolidation techniques which were relatively new were amongst those considered.

English Industrial Estates Corporation had also met similar conditions on its brownfield sites, and, at about the same time, had undertaken its own investigation of the technique. At Blyth in Northumbria vibro compaction was used in place of ordinary piles to overcome the effects of high pH values of the restored brown field site, the ground surface being adequate for the support of the factory floor.

The technique was later recalled by Hall (2009) as having been described to him as:

> *"... a hole was first made into the ground by a vibrating tool hung from a crane, withdrawn and the resulting hole filled with stone of suitable grading. The vibrator is again inserted into the hole and the stone compacted, the vibrator again withdrawn, stone tipped into the hole and the vibrator inserted, the process being repeated as necessary, the theory being that on completion, the "cement free" column of stone can gain sufficient resistance to spread into the surrounding virgin ground."*

This same approach was undertaken at Cambuslang Industrial Estate for one or both of the first two units, for both individual columns and the general floor area, after seeking advice from specialist contractors.

To prove its adequacy, future column locations were load tested, appropriate kentledge and support having been brought in.

As well as standard boreholes for soils investigation, static cone penetration tests were carried out for a further unit. The report (Fugro, 1977), stated that

> *"the self weight of 2m of fill will cause settlement....estimated to be of the order of 80 to 120mms", and that the soil conditions would not be adequate for shallow spread or raft foundations."*

It was also suggested in the report that surcharging the area with an additional 4.5m of fill, carefully placed in layers at the rate of not more than 1m to 2m per week to avoid shear failure of the underlying soils, would then permit the subsequent use of pad foundations with a bearing pressure of 100kN/m^2.

Accordingly, the additional surcharge was provided and settlement was measured over a period of approximately 22 weeks, using an arrangement similar to that depicted in Figure 7.

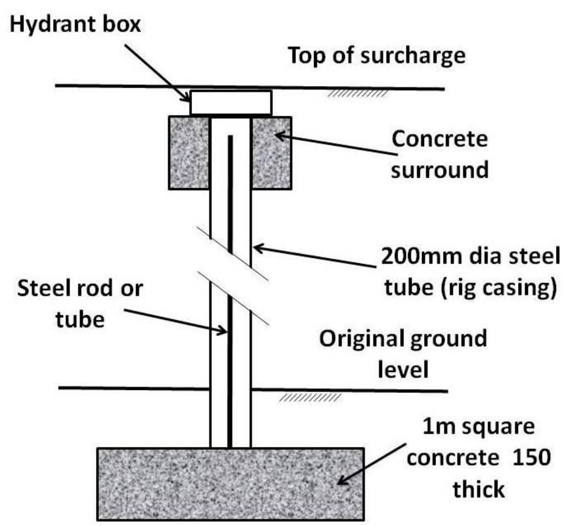

Figure 7 Arrangement for measuring settlement and consolidation

Earlier estimates of the order of 135 to 270mms compared with observed settlement of 98mms.

A further report (Thorburn and Partners, 1977) which dealt with the variation in calculated settlement concluded that

> *"the alluvial soils are not normally consolidated but possess geological stress histories"* and that *"permeable layers promote a rapid dissipation of excess pore water pressures induced by the surcharge".*

The history this referred to was that there was evidence of earlier fill material from 2m to 4m thick in parts of the site, this being colliery spoil and other waste that had not been removed. The area under discussion had once been part of the north colliery tip, and had previously been consolidated as a result. The use of surcharge had been successful.

Fugro, (1978) carried out a further ground investigation across a large area of the site, intended to cover the approximate location of several future units. A total of 31 static cone penetrations revealed conditions as in Table 3:

Table 3: Summary of superficial deposits

Blaes Fill	Up to 4m of imported fill material, as expected
Sandy Clays, silty clays, silt and sands	1 to 4m
Sand and gravel	2 to 4m
Laminated silty clays and silts	Up to 19m
Sandy clays with gravel, cobbles and boulders	Up to 6m
Sandstone or shale bedrock	

The investigation included cone penetration tests on the surcharge material which was still in place, the report concluding that any settlement following immediate removal of the surcharge and construction of the intended unit would be acceptable.

Their report also discusses the settlement that would occur in the blaes fill itself, this having been in place for two years, and in the subsoils. It concluded that,

> *"...on the basis of available data, the quality of compaction is more than adequate and that foundations placed in this material should experience almost negligible settlement of the order of about 5mm due to the compression of the fill itself".*

But there was an important provision:

> *"...the material should remain above the water table and is protected from prolonged inundation and flooding from external sources".*

With surcharging having been successful, the technique was used for developments at Hamilton Farm in 1980. However, in 1994 there was severe flooding resulting in the need for extensive works raising the ground in some areas and in providing protection works to cater for what is understood to be a 200 year flood.

The additional load from the fill would also induce consolidation, and, following that work, other areas have been developed, using surcharge on a rolling basis from unit to unit.

In addition, mine workings have been consolidated to enable development on areas which had previously been unused.

CONCLUSIONS

Figure 8 in about 2006 shows the extent of the development on the original Cambuslang Industrial Estate and the neighbouring areas formerly the sites of Colvilles Clugston Shanks and Hamilton Farm. The site's history, the manner of removal of coal, and the absence of accurate and complete records of previous uses made the job of redeveloping the area complex. However, all sites require research to establish their complete condition and suitability especially where conditions are hidden.
Over 30 years after development began the site has now completely changed, but development continues.

From the work covering these thirty years we can conclude that

- The regeneration of a brownfield site this extensive is complex, taking time as well as money, for which there needs to be clear commitment at an executive level, and a willingness to ensure that the work that begins can be sustained.
- It will involve many organisations and their staff, for which a strong sense of purpose and teamwork are essential; working together in this case to achieve sustainable economic development;
- Geotechnical aspects are fundamental to all site developments, and are of particular importance where sites have had previous purposes. As engineers we need to enable our clients to understand the issues that they face, options for dealing with the issues, and the costs and timescales involved;

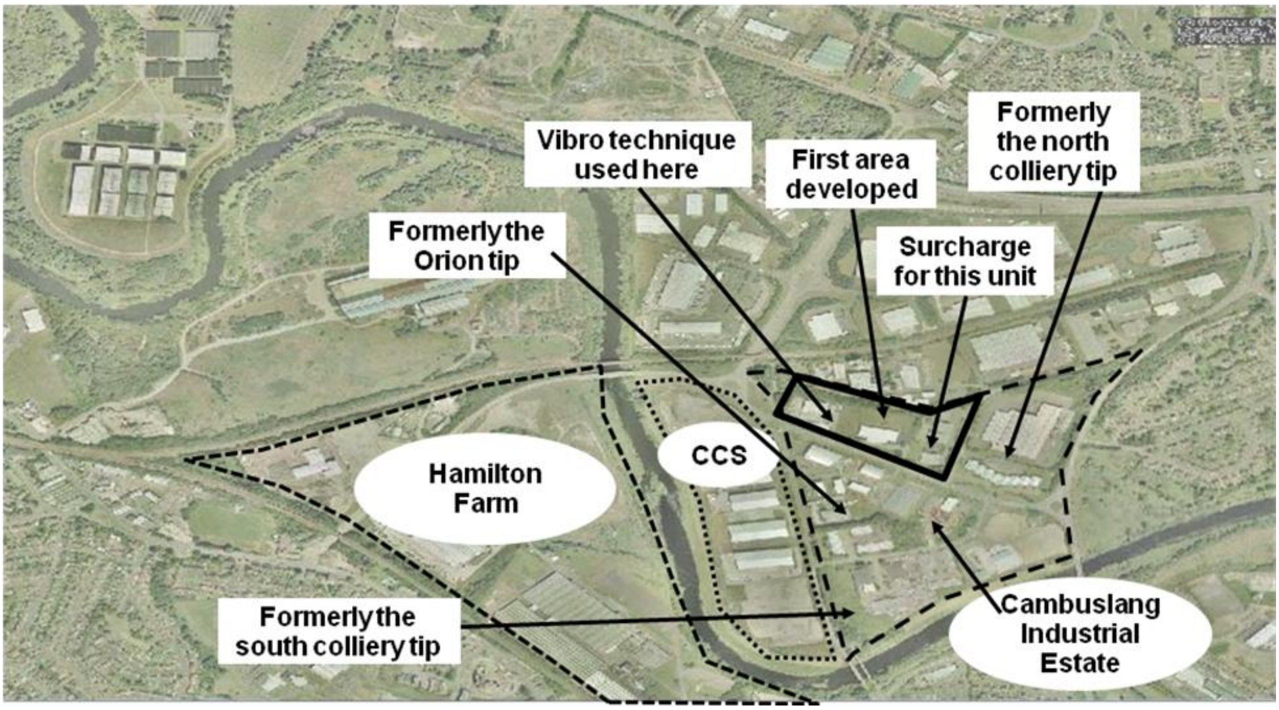

Figure 8 Scottish Enterprise (2006) Aerial photograph identifying the areas, developments and history

- In order to minimise subsequent surprises during development, the research should be thorough, using as much available historical material, local knowledge, and detailed soil and mineral investigations as possible;
- Investigation is progressive, working from the general area to the specific site location, especially necessary where there are known or expected variations in ground conditions;
- The provision of earthworks, both cut and fill, alter ground conditions, so the effects require careful consideration;
- Regulations change, knowledge increases, and it is vital that early experiences of value to subsequent work are retained;
- We must keep abreast of new developments in techniques for ground investigation and treatment, so that we are able to consider options for dealing with them. In particular, since the 1970s when the work on this site began there have been many developments in ground exploration techniques which will be of increasing value in the investigation and development of brownfield sites;

For success there needs to be the political and financial will to enable the provision of developments to cater for society's changing needs. These are reflected in the sites considered in this Paper which made the transition from heavy industry to light industry with other commercial developments, a major change to the area which is still continuing 30 years after redevelopment began.

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Ordnance Survey for relevant permissions

British Geological Survey for relevant permissions

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