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Dalton By-pass: site investigation in an area of abandoned haematite mine workings

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Summary

The choice of the public for a route for the Dalton By-pass lay through an extensive area of well-worked and abandoned haematite mine workings. The geology of the area and the method of mining are described, and the reasons are given for the selection of the preferred route.

The problems associated with the route are discussed, together with the detailed planning necessary to organize an extensive complex site investigation, involving almost 700 boreholes in a roadway length of $4\frac{1}{2}$ km. A typical cutting is examined in some detail to illustrate the contractual and technical problems connected with the required excavation of a cutting slope directly over a major iron ore sop; these problems include the removal and treatment of the water-filled collapse cone over the rubble-filled cavern left by the ore extraction. The relative costing of an elevated structure and an embankment founded on collapsed workings are discussed.

Some engineering conclusions are drawn from the site investigation regarding the suitablty of embankment fill, the rate of settlement of embankments on alluvium, and the stability of a rock slope.

The site

Dalton is situated on the A590 in the Furness Peninsula, Cumbria, 3 miles NE of Barrow (Fig. 1). The Dalton By-pass is one of 12 improvement schemes between Barrow and Levens Bridge, Kendal designed to improve communications between SW Cumbria and the M6 Motorway. Nine of these schemes have been completed or are under construction, but the remaining three, including Dalton By-pass, are still at the site investigation stage.

Geology

The western part of the route passes over Permian rocks, but the main part lies over Carboniferous limestone. The geological succession is as follows:

Pleistocene	Glacial deposits
Triassic	Miscellaneous Breccias
Permian	St. Bees Sandstone
	Brockram Beds
Carboniferous	Urswick Limestone
	Park Limestone
	Dalton Beds
	Red Hill Oolite
	Martin Limestone
	Basement Beds.

Within the Lower Carboniferous Limestone group are worked out haematite iron ore deposits of considerable size, known locally as 'sops' or 'flats'. The haematite deposits, which comprise nearly 50% recoverable iron, were formed in two different ways:

(a) by molecular metasomatic replacement of solid limestone (most of the deposits); and
(b) by the infilling of pre-existing solution fractures and caverns.

The flats were formed by the metasomatic replacement of beds of limestone in the vicinity of major faults. The proposed route passes over vein deposits or flats at the western and eastern ends, but all other major deposits *en route* are sops.

The sop deposits are irregularly shaped bulk masses of ore, with typical dimensions of 60 m across by 60 m deep, many of which originally outcropped at rockhead with only a covering of glacial clay. Examples exist to demonstrate that lateral extension of major sops have been worked out and now comprise subterranean caverns with bridging limestone roofs.

The latest view of the Institute of Geological Sciences (I.G.S. 1977) on the mode of formation of these ore deposits is as follows:

During Permo-Trias times, exposed highland areas developed deep lateritic soil horizons which provided iron in a form which could, by weathering processes, be washed down and incorporated in the newly forming St Bees Sandstone. Subsequently, this sandstone was depressed by tectonic subsidence to a depth of perhaps 2.5 km, where ground temperatures exceeded 100°C. It is believed that this sandstone contained hypersaline brine as interstitial fluid, which was driven laterally upwards through the St Bees Sandstone by increasing tectonic pressure, probably in late Cretaceous times. As the fluids passed through the sandstone, they leached out the indigenous iron and became iron-rich. As the fluids reached the present region of

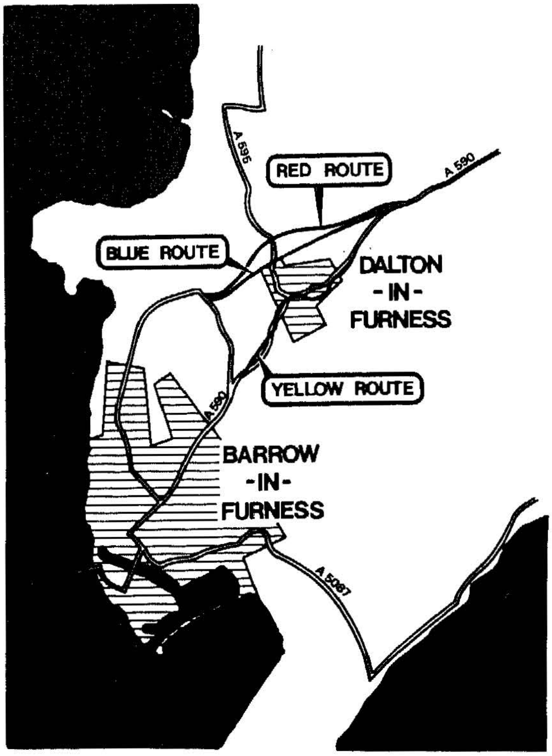


FIG. 1. Site location plan.

SW Cumbria, they came into direct contact with the upper surface of the Carboniferous Limestone, which here directly underlay the sandstone. The chemically-replaceable limestone contained abundant faults and fissures, and some fossil karst features, and the warm ferrigenous fluids descended into these, causing the formation of the present sops and flats. Some of the St Bees Sandstone collapsed into the karstic hollows during the mineral replacement/emplacement process, thus explaining the presence of that sandstone in situations far away from present outcrops. The overlying St Bees Sandstone and other beds have subsequently been removed by erosion, thus leaving the Carboniferous Limestone exposed as at the present day, together with its sops, veins and flats. Solution of the limestone continued through geological time, resulting in the formation of non-filled cavities, and the disturbance and brecciation of the ore deposits. This solution of the limestone is still in progress, and manifests itself in the occasional settlement of the ground surface.

Mining

Haematite ore has been worked in these regions since at least the early thirteenth century. However, polished stone tools have been found in workings in Furness, so the mining could have taken place even earlier. Most of the ore was removed in the nineteenth century and formed the basis for the ship building industry of Barrow (Holland 1976).

The ore was largely found in sops, bowl-shaped depressions in the Carboniferous Limestone. Where the limestone roof was absent or very thin, the overlying glacial deposits subsided as the ore was removed, creating the spectacular craters that are a feature of the district (Fig. 2). Another feature is the very large number of shafts, mostly driven to locate ore bodies and indifferently filled, or partly filled with timber staging some distance below the surface. The shafts are a continuing danger, as the timber is liable to rot

FIG. 2. Typical ponded mine sop.

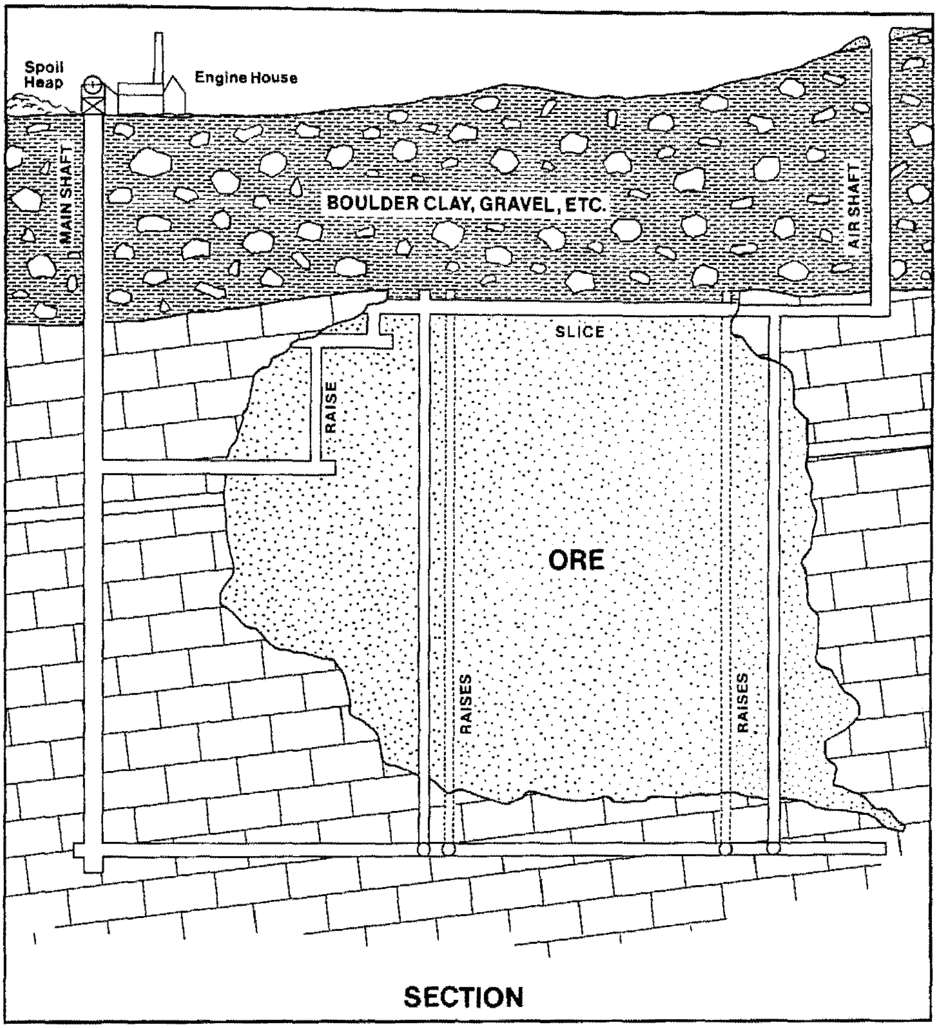


FIG. 3. Cross-section of a sop showing method of working.

leading to collapse of the infilling and surrounding ground.

Having located an orebody the practice was to sink a shaft, outside the influence expected from the subsidence of the workings to at least the depth of the ore-body. From these levels internal shafts or raises were put up through the ore to the top of the deposit. (Fig. 3). They served as ladderways or manways and particularly as ore passes. At the summit of the deposit the raises were connected by sublevels or drifts and the top slices further divided into conveniently sized blocks or pillars. These were then removed in rectangular segments, usually working towards the raises. Truck loads of ore were trammed along the sub-levels and tipped into the raises. These acted as hoppers, the ore being drawn off at the bottom, loaded into trucks, trammed to the shaft foot and there lifted to the surface. At convenient points access, pumping and ventilation shafts led to the surface.

The roof was supported by heavy timbering, which crushed when the ore was taken out and the props removed for re-use. As each slice was worked away fresh sub-levels were driven below it and the process was repeated. The timber mat increased in thickness until, eventually, the bottom of the deposit was reached. Sometimes the roof did not collapse immediately, but the void crept towards the surface collapsing without warning at a later date. Voids and collapses occur even in areas unconnected with mining activities, due to water solution of the limestone.

Figure 4 shows a typical mine working complex in the Dalton area with mine workings, shafts, etc.

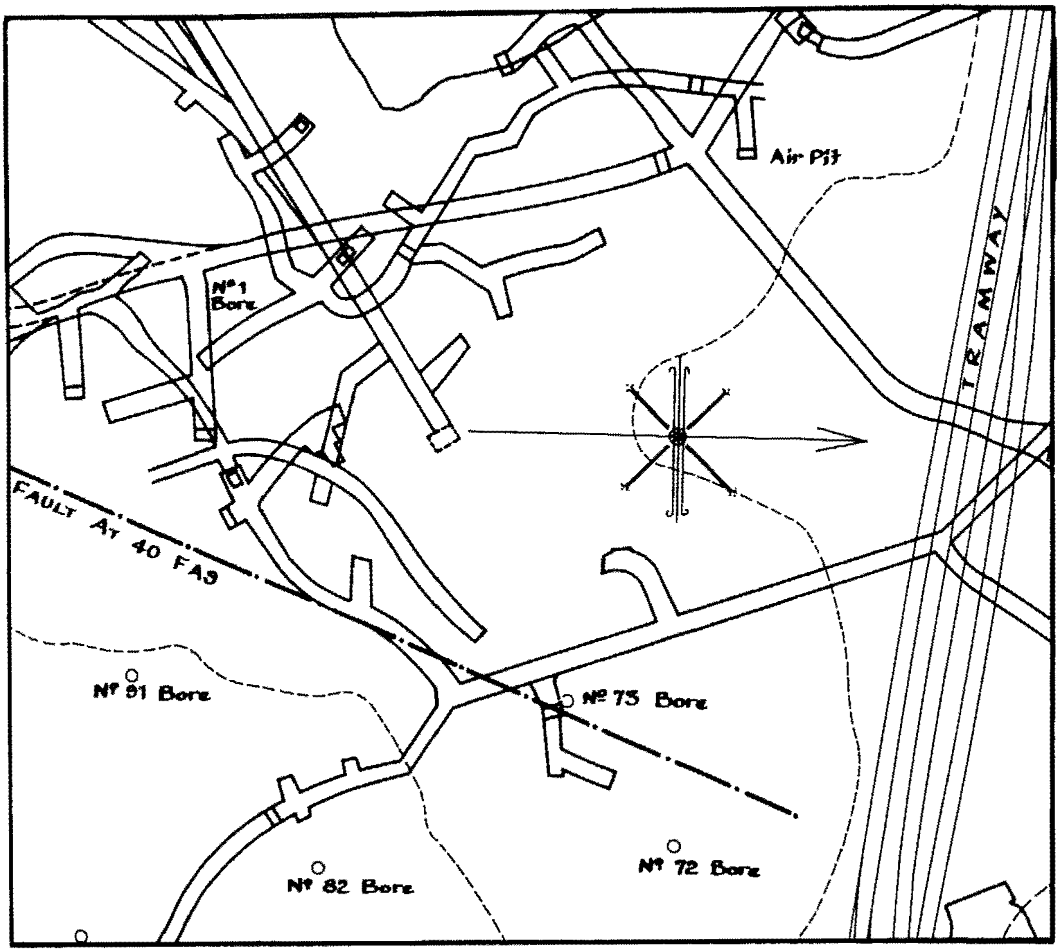


FIG. 4. Close-up view of a typical original mine plan.

Choice of route

It is normal practice in the Department of Transport to consult the public at an early stage on the choice of route; Fig. 1 shows the three routes offered to the public.

Route C (Yellow) is the shortest and cheapest, but crosses the built-up area of Dalton, and involves the demolition of 56 dwellings and 2 public houses. Route B (Blue) would be visible from Dalton over parts of its length, and involves the demolition of 4 houses, while Route A (Red) is hidden from Dalton town, involves no property demolition but passes through the area of known old iron ore workings. It takes little imagination to guess that the public chose line A, which presents the most severe engineering problems.

The first task of the site investigation was to seek out all available mining records from both official and unofficial sources. These records were plotted on a 1/2500 scale survey and reported as a desk study (Fig. 5). It will be seen that by slight adjustment line B can be made to avoid most of the mine-workings, so the consultant proposed a revised line B. Once more the views of the public were sought and as no serious objections were forthcoming this line was selected and preparations made for the detailed site investigation. Because of difficulties which had been experienced on other schemes in carrying out site investigation work after the line of the route had been officially advertized, it was decided to make this survey as comprehensive as possible. It was also necessary, for economic reasons, to try to avoid the old workings and this called for a detailed survey.

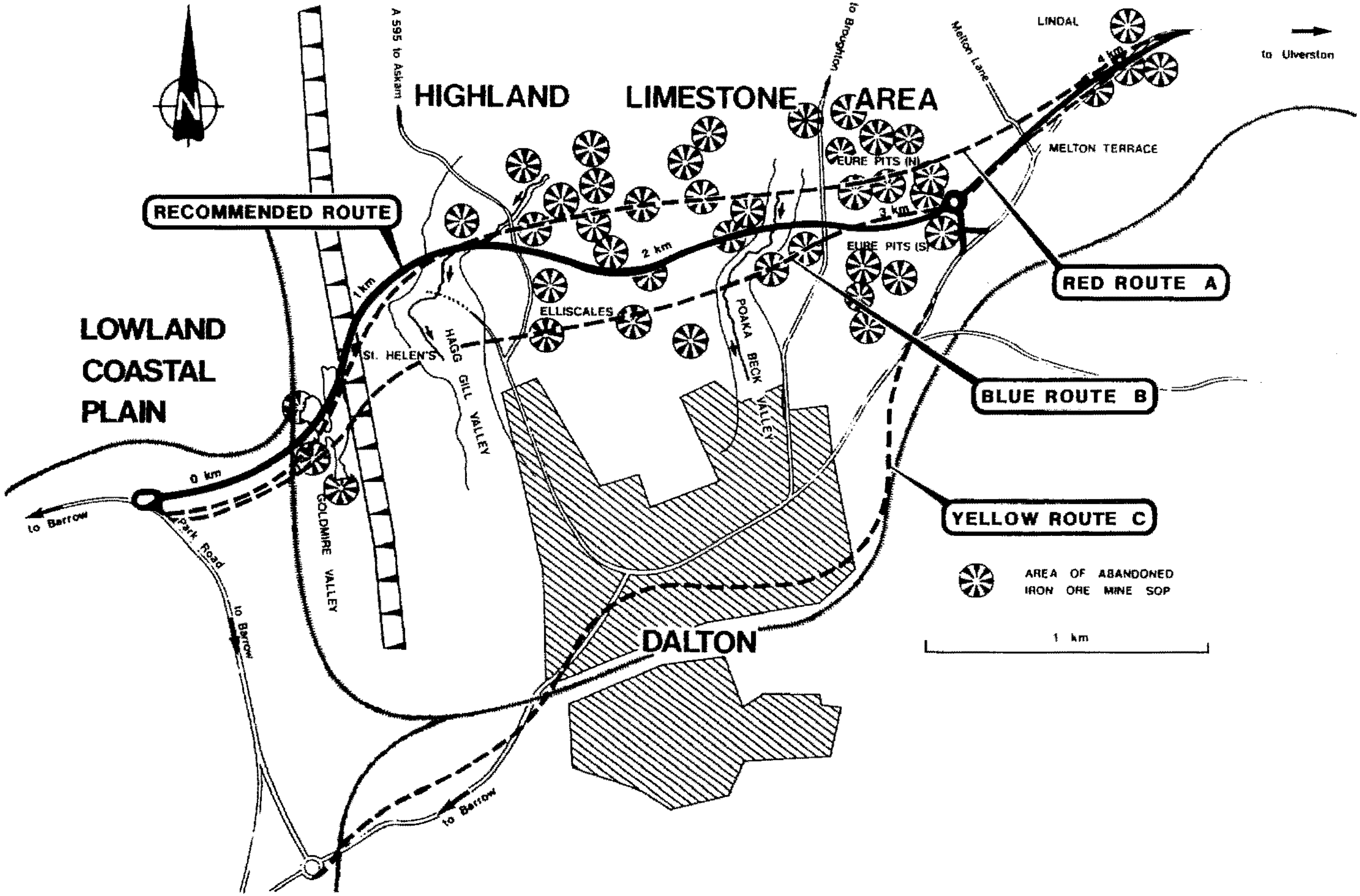


FIG. 5. Alternative routes and mine sops in relation to Dalton.

Site works and data presentation

Early consideration was given to two major points which were to provide the over-riding guidelines for the entire project. The first aspect, of fundamental importance, was that of controlling a site on which more than 760 boreholes had to be drilled within a 9-month period, on which, simultaneously, a full geophysical investigation was to be conducted, and along which most of the 20 different land owners were unhappy with the presence of site investigation machinery on their agricultural land.

In order to ensure that a full record of the site was made before any works were started, a complete Centre-Line Survey was undertaken with coloured photographs looking in both directions along the route at 100 m intervals. Additionally, a complete Site Condition Survey was undertaken of all fields along the route and a substantial distance to the N and S of the route. It was considered that these would be of value both in terms of assessing Contractor's claims, and in assessing land owner's claims immediately subsequent to the Site Investigation works, and also during the course of any future construction works.

As a particular method of controlling the site investigation works, a Site Access Report was prepared prior to site works commencing. This involved the detailed study of each field requiring access, and an assessment of preferred access points and routes, together with any necessary temporary or permanent remedial works. This report contained diagrams of each field to be entered and photographs of all access points and proposed routes. Subsequent to the completion of the Site Investigation works, a second Site Condition Report was prepared to confirm the condition of the site and any reinstatement work.

The second aspect, which required considerable thought prior to the commencement of the work, was the handling and ultimate presentation of the extremely large quantity of data which would be derived in a relatively short time from the complex work programme. To handle this, a full-time surveying team was sent into the field considerably in advance of the site investigation to peg-out the centre-line of the route, the geophysical investigation squares, and to up-date the detailing on the topographical plans. Up-to-date 1/500th scale plans were not available, so 1/2500th scale plans were optically-enlarged and the field data entered upon them (Fig. 6).

Since the use of maps was to be the primary means of conveying information, it was essential that some coherent system of plotting be adopted. In order to maintain accuracy of plotting and reproduction, it was decided that all data would be plotted relative to the left-hand lower corner of each 100 m National Grid square. There is a problem in reconciling accurate modern surveying techniques with reproducing machines that distort scale. Although a full list of

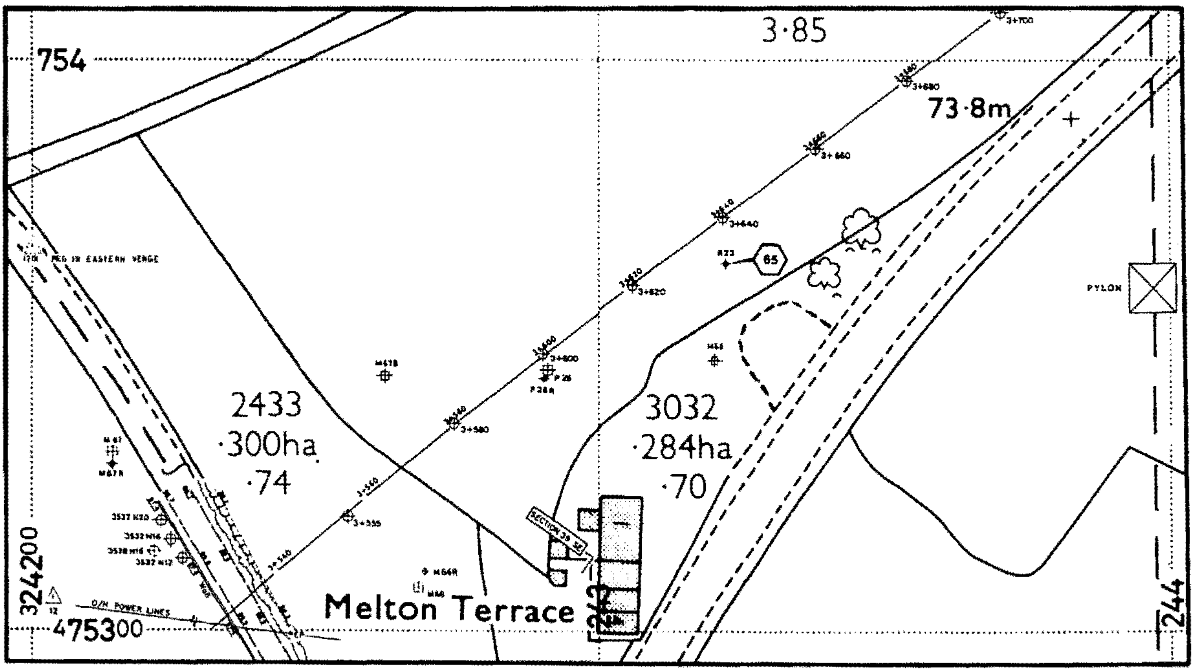


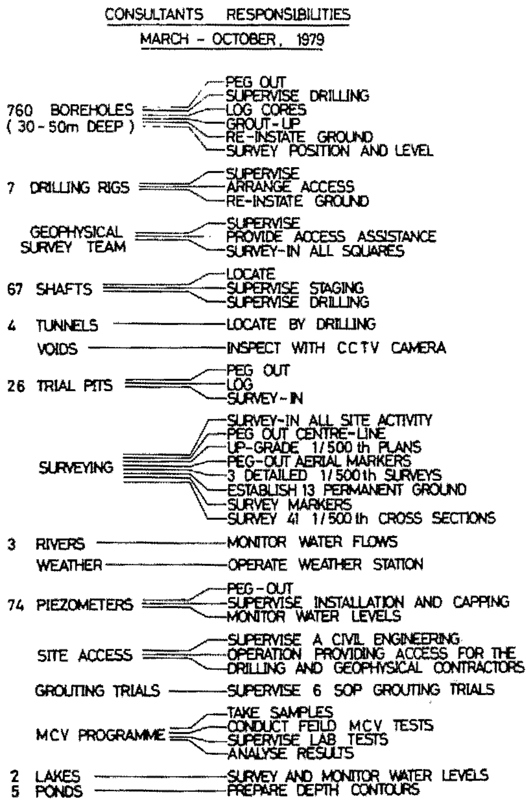
FIG. 6. Illustration of 1/500th scale plan demonstrating data plotting method.

National Grid co-ordinates was provided for every point represented on the plan, none-the-less information is much more often assessed and much more easily available directly from the plan, and therefore it was considered that this step was necessary to maintain the accuracy of plotting. It can be seen on Fig. 6 that this results, for example, in the slight offsetting of the centre-line as each 100 m square is crossed. Similarly, where necessary, the optically-enlarged detail was adjusted by field survey so that structures could be accurately placed on the plans prior to the subsequent production of an accurate 1/500th survey plan from aerial photographs.

Project description

Table 1 shows the complex activity being undertaken on the site.

With so many boreholes and a full geophysical survey to be presented, and so many mine shafts and mine workings to be plotted, it was decided that the appropriate scale for the plans would be 1/500th. The route was therefore divided into 26 1/500th scale plans; since there are so many aspects of the route which could be individually described, discussion will be limited to the construction problems revealed by



the investigation at Elliscales Cutting, and a typical representative embankment which is proposed across Poaka Beck valley.

Elliscale cutting

The main problem in connection with the construction of this cutting is the stabilization of Sop 7 and its two associated mine shafts. The sop itself is ponded within the collapse zone of the underlying abandoned haematite workings.

The mine workings and the shafts produce a compound zone of potential instability which adversely affects the cutting N of the proposed carriageway (Fig. 7). The main problem is to recommend a suitable construction procedure which would take account of safety requirements with respect to plant being involved in the operation of excavating the carriageway cutting. It was considered that a contractor would be unlikely to wish to allow plant to operate over the top of a sop, or within influencing distance of that sop, during the course of excavation work. It has therefore been recommended that the sop pond should be drained by pumping, and back-filled with cohesive material. Following this, light drilling rigs and grouting plant could be brought over the sop and a grouting operation conducted to stabilize the workings. The drilling operations within the sops has revealed that they are primarily rubble-filled collapse zones, with little in the way of open caverns. Consequently, a grout intake of the order of 25% of the total sop volume is to be expected. After the sop has been grouted, the cutting could be excavated by normal methods and then the back-fill material from the pond (which extends nearly down to proposed carriageway level) could be removed and replaced with granular fill and suitable land drains.

This solution is typical of the approach that will be necessary to stabilize the sops and vein workings along the length of this route.

Cavity resonance survey

A cavity resonance survey (Fig. 8) was recommended in order to attempt to locate and record mine shafts along the route. The high frequency of recorded workings, shafts and trial shafts led to the view that some unrecorded shafts would certainly exist, some of which would have no surface manifestation. Furthermore, prior to site work, the detailed mine plans for two areas of known workings on the centre-line, had still not been located. The most effective method of shaft location—total ground strip—was not available as an alternative, and it was considered that it would not have been correct to make no attempt to locate shafts. Cavity resonance was selected because it was one of

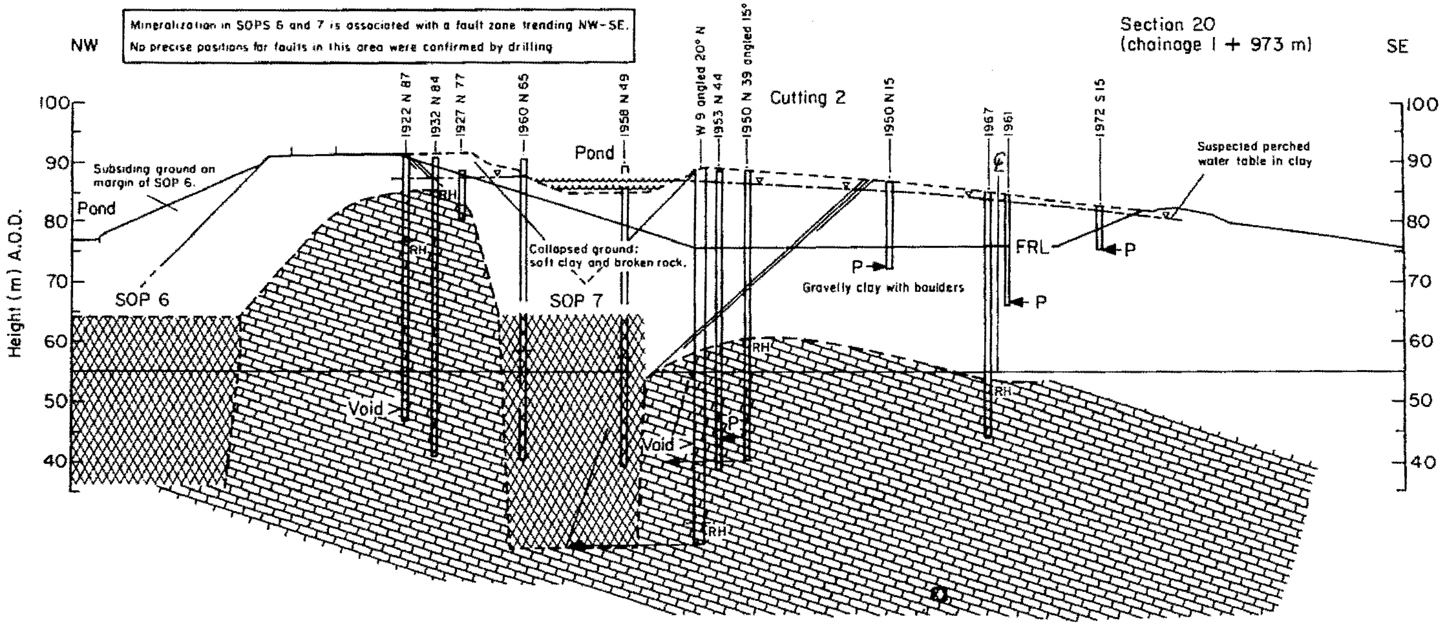


FIG. 7. Geological section across elliscales pond and cutting.

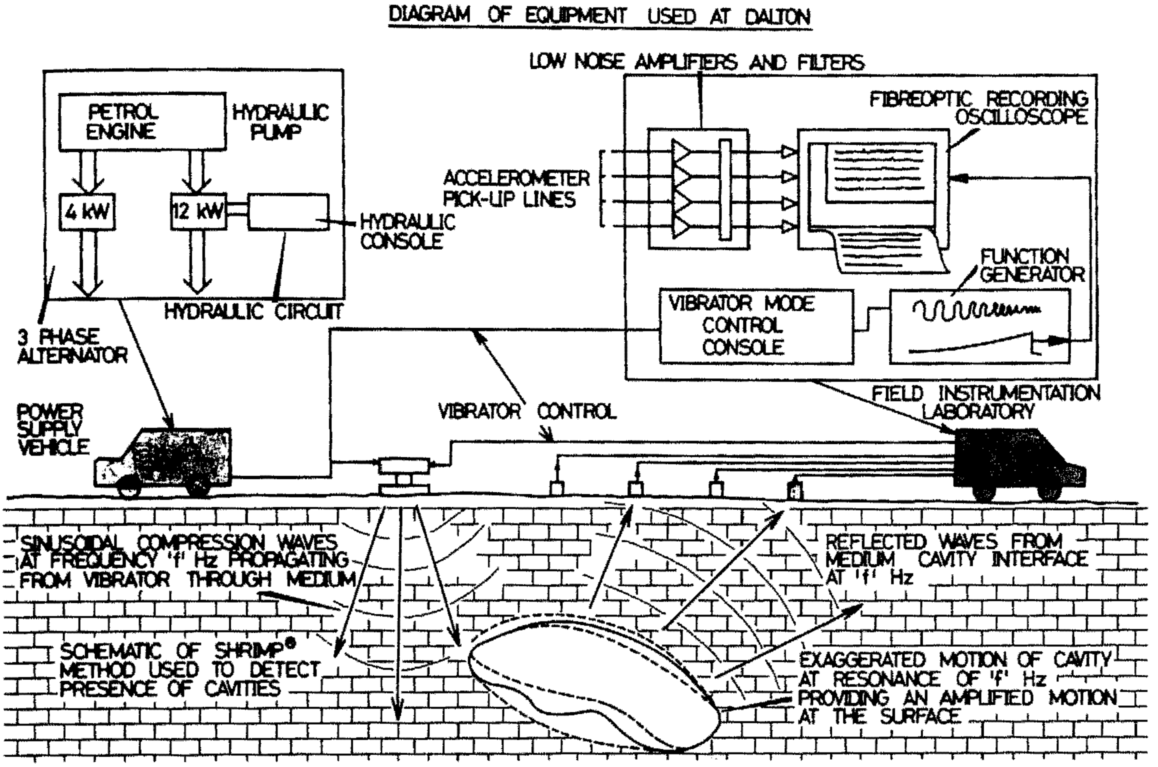


FIG. 8. Method of operation of the cavity resonance system.

the newest techniques available, and because the site conditions, as expected at the time, appeared to be suitable for the performance claimed by the geophysical contractor, for shaft location. In addition the technique held the possibility of locating large voids should these exist beneath the route, thus providing a potential safety guide for the drilling contractor's plant.

After several weeks of work it appeared that the cavity resonance system was not proving to be cost-effective, and was not providing useful information. The field equipment appeared to be particularly susceptible to humidity and field disturbance such as rain, and vibration from traffic and drilling rigs. The ground vibrations also appeared to be affected by near-surface features such as areas of back-fill and old railway track. The premature termination of the geophysical work was recommended, and was undertaken in accordance with the procedure specified in the contract documents.

Poaka Beck Embankment

Poaka Beck embankment presented a number of hydrological, mining, slope stability, and environmental problems (Fig. 9).

As initially proposed, the southern embankment slope at the western side appeared to be potentially unstable, and slope benching was recommended in order to attempt to improve stability.

Sop 12A lies directly beneath the embankment, and a drill-and-grout-zone is recommended to cover the workings in this locality. It did not prove possible to obtain any detailed mine working plans in this vicinity, but such records as were available suggested that the workings were small and limited to the area enclosed within the grouting box shown on Fig. 9. The four shafts within the sop area require drilling, grouting and capping at a firm horizon.

Shaft 42 has a zone of potential instability which overlaps the base of the embankment slope, and it is therefore considered advisable to drill-and-grout this shaft. However, since the carriageway itself is not nearby, it is not considered necessary to cap the shaft. Shaft 43 just NW of Sop 12A has a zone of potential instability which extends over the recommended drainage line from Sop 12 to Poaka Beck. This drainage channel would only be a minor structure and would not, in itself, merit Shaft 43 being grouted. However, if the drainage line were to be broken and water seepage occur in a hollow at that point, then slope instability could follow on the northern slope of

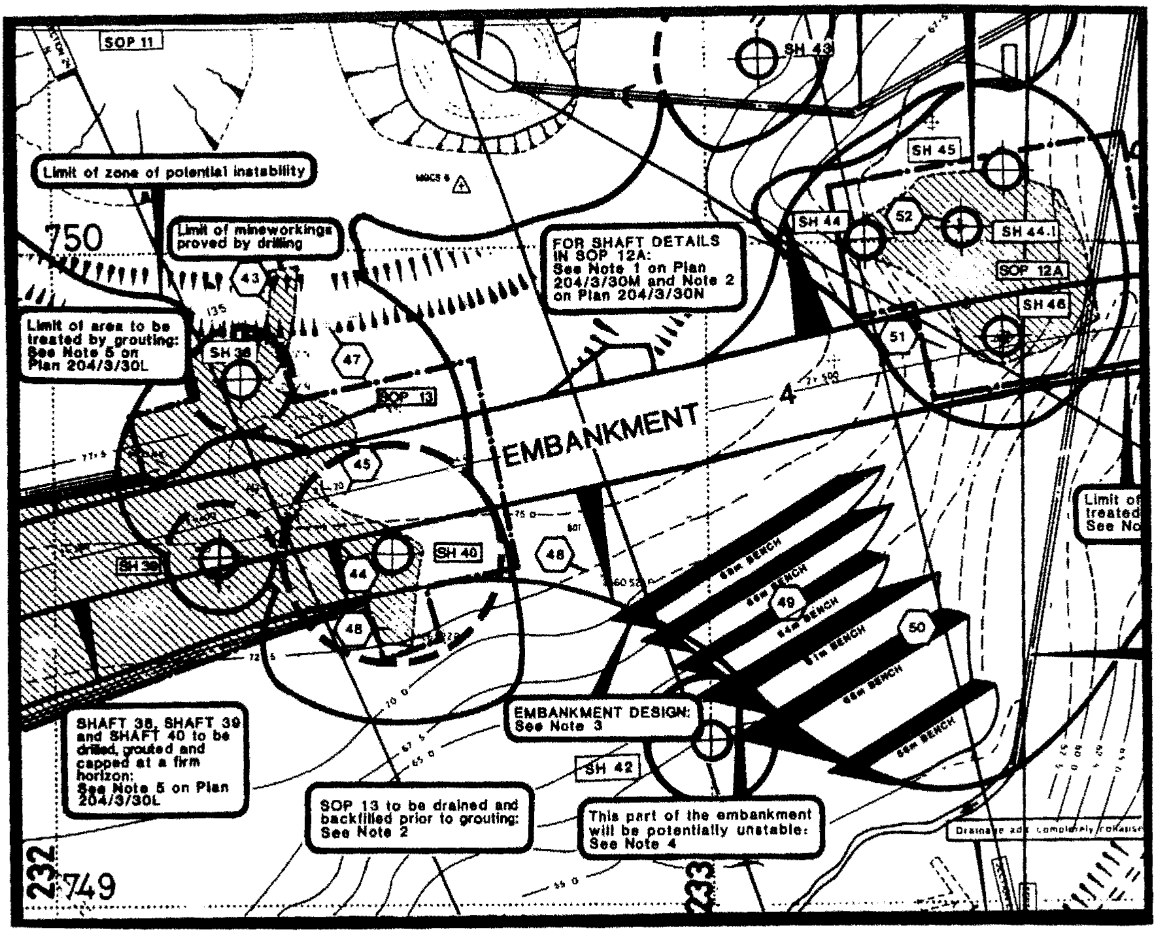


FIG. 9. Illustration of the 1/500th scale plan of Poaka Beck.

the proposed embankment. It has therefore also been necessary to recommend that Shaft 43 be drilled and grouted, but not necessarily capped.

Sop 12 is another ponded sop, and will have to have its water level lowered in order to reduce the standing water table height in the higher ground above the embankment.

Site access to the floor of Poaka Beck was particularly difficult owing to the steep slopes of the valley in this vicinity. Nonetheless, the survey team prepared a detailed contour plan of the valley crossing point, and access routes were designed and constructed for the rigs. Many boreholes were drilled and trial pits excavated. The results of the borehole were difficult to analyse, since the floor of Poaka Beck at the crossing point was covered with thick superficial deposits, and yet, nearby to both N and S, bedrock limestone outcropped at valley level. The rise and fall in water table in the adjacent fissured limestone rocks, combined with the regular release of water from a reservoir further upstream, meant that the valley floor was sometimes dry, and sometimes contained a briskly running stream. Sink holes could be seen further N where the river disappeared into the bedrock. In view of the rapidly-fluctuating water table at this locality, it is recommended that any embankment base be constructed on a granular drainage blanket protected from contamination by a fabric filter membrane.

There is concern with the potential vulnerability of this embankment and its river culvert to blocking at the upstream end. There is no reason to suspect any particular susceptibility to blocking but it has to be borne in mind that the embankment is upstream from Dalton town and, if the culvert were to be blocked, then the embankment would in effect, become a dam. In view of the fluctuating water table and the fact that, the reservoir to the N also discharges relatively large quantities of water into the stream at regular intervals,

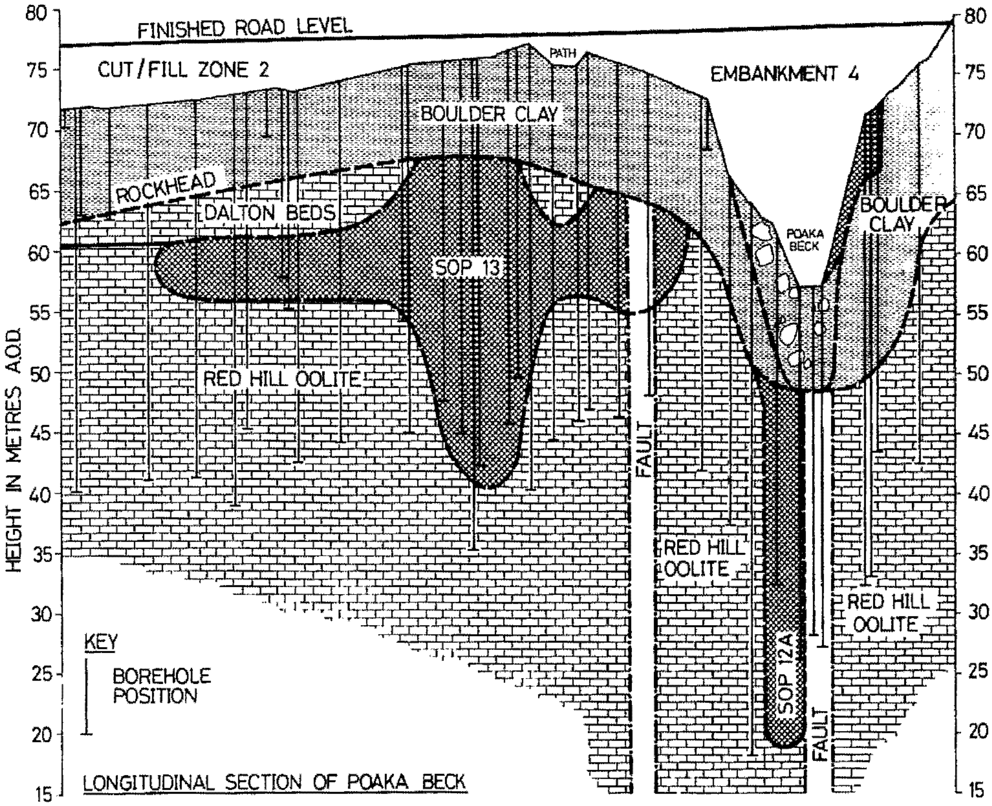


FIG. 10. Geological longitudinal section of Poaka Beck valley, showing sop.

were a blockage to occur at an inopportune time the downstream consequences of a failure of the 'dam' could be very serious.

In view of this possibility and of a possible fill short-fall for the route as a whole, it was considered sensible to assesss the cost-effectiveness of an elevated structure across the valley. Normally, such a structure would be much more expensive than the equivalent earth embankment, but in these special circumstances, where considerable extra works relating to the stabilisation of mining shafts and mine sops are concerned, there seemed a good possibility of financial economy.

When the expense of stabilizing mine shafts and mine workings is taken into account, together with the cost of the imported fill, then the cost for the two structures becomes virtually the same. This allows the aesthetic aspects of the valley environment to be considered and makes the proposition of an elevated structure very attractive. It is interesting to compare this with the cost balance in Goldmire Valley where, despite taking into account the stabilization of the mine working and the high cost of excavating 3 m of peat an elevated viaduct still transpired to be some 20% or so more expensive than the equivalent fill embankment.

Of course, decisions of this kind never tend to be easy and, as can be seen in Fig. 10, the deep superficial deposits in the floor of Poaka Beck at the crossing point, and the irregularity of rock-head determined by the boreholes, lead to the conclusions that the crossing is being proposed at the point of a collapsed limestone cavern. Since a river disappears into swallow holes just to the N of the proposed crossing, and in the context of the general problems posed by limestone river valleys it can be anticipated that the valley floor will not be stable in the long-term. In the event of minor movements owing to settlement, an embankment would certainly be a more flexible structure than a bridge and in pure engineering terms, as opposed to environmental and aesthetic terms, it might be the better alternative.

Concluding comments

Increasingly, roads are having to be constructed on inferior land as the better land is occupied by housing and agricultural interests. This presents a challenge to the soils engineer and the engineering geologist, but inevitably increases the costs of roadbuilding.

The cost of this site investigation approaches £250,000 per km. However, the cost of treating the mine workings is so large that the expenditure on the investigation is justified by the savings arising from the avoidance of the worst of the workings. Furthermore, a detailed investigation allows the reliable design of structures where they are unavoidably to be built over abandoned mine workings.

NOTE. The comments made in this paper are the personal opinions of the authors and are not necessarily those of the Department of Transport. The authors wish to express thanks to the Chief Engineer of the Department of Transport, for permission to publish this paper.

References

INSTITUTE OF GEOLOGICAL SCIENCES 1977. Geology and Haematite Deposits of South Cumbria *Rep. Inst. geol. Sci.* **58/48**.

MANSTOCK GEOTECHNICAL CONSULTANCY SERVICES LTD. 1980. *Site Investigation Report on the Dalton By-Pass*, (unpubl.).