RAILWAY ENGINEERING 2000
SITE INVESTIGATION FOR PERMANENT WAY MAINTENANCE DESIGN

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ABSTRACT
The determination of the geotechnical profile of railway embankments or cuttings is an essential pre-requisite for remedial or new works design.

Conventional site investigation techniques using standard cable percussive and rotary drilling plant are rarely feasible for permanent way investigations due to the requirement for safety zones and the problems associated with securing possessions for this type of work. This has forced the industry to find alternative methods of investigation particularly suited to moderately steep slopes. The constraints do involve a degree of compromise, but by using the techniques in a phased manner, decisions on the need for greater sophistication and cost can be focussed on the areas of major problem.

Embankments form a significant part of the railway network and these are frequently composed predominantly of clay fills. The history of embankment construction is often not well documented and it is suspected that the only compaction was by the vehicles transporting the clay along the route. The majority of embankments are therefore composed of poorly compacted fills.

The investigation of embankments showing signs of distress requires not only reasonable quality sampling and insitu testing, but also monitoring. Geotechnics

Limited has established a range of investigation techniques, which can address these requirements and includes window sampling, dynamic probing, mini-auger drilling and hand-excavated trial pits. Hand vane testing and the insitu CBR probe can provide invaluable data on strength and sub-base quality.

A range of monitoring installations can be provided including slip indicators, piezometers and inclinometers.

There are of course some embankments which do not lend themselves to investigation by light weight equipment and a much more costly investigation using larger equipment capable of being dismantled and re-erected at exploratory hole locations or lifted on by crane becomes a necessity, usually on scaffold platforms.

INTRODUCTION

The recent investment proposals to maintain, improve and upgrade the U.K. railway network has put a demand on the site investigation industry to offer alternative techniques for testing and sampling of the ground in areas of restricted access, increased safety requirements and short timescales. Previous papers have considered non-intrusive geophysical techniques which can be used to identify anomalous and potential problem areas but these all need to be verified and investigated before solutions can be determined. There is generally little or no historical information on the foundations or construction of old railway structures and thus new investigations are needed on most sites.

Railtrack has also identified a requirement to develop unused areas of their vast property and land assets. These also require investigation, not only of geotechnical characteristics but also, with new legislation on the environment being implemented, the extent of any contamination that may be present on the site. These sites are frequently adjacent to live railway lines and the need for stringent safety standards is again of paramount importance.

All areas of the railway network are being evaluated, initially by visual examination and reference to historical maintenance records and subsequently, sometimes by geophysical techniques to identify problem areas and eventually by intrusive physical techniques. The most common areas and structures necessitating site investigation to provide geotechnical solutions are embankments and bridges. Embankments normally exist to raise the track level to maintain acceptable gradients or avoid flooding and are therefore frequently founded on poor ground such as alluvial flood plains. Bridge foundations impose higher than normal loads on the underlying soils and the imposition of new decks may change the loading conditions and thus the behaviour of the soil. Such changes may affect the interaction of the bridge with the adjacent track.

In areas where new tracks or structures are required extensive investigations are required to determine the soil ground model for foundation design, slope stability evaluation and earthworks specification.

THE PROBLEMS

The study of historical maintenance data combined with visual assessment of the permanent way structures is the most common method of identifying problem areas on the railway network. Such studies will normally identify areas which appear to be most at risk and this system has been used in some areas to prioritise further investigation and remediation work.

The catastrophic failures of railway permanent way structures are normally well documented and generally involve large-scale soil failure in some way. This can be embankment failure resulting in loss of track or slope failure from above in cuttings and sidelong ground resulting in soil inundation of the track. The objective of the present investment in a maintenance programme is to prevent catastrophic failures and thus major disruption to the network.

The most extensive records that can be used for identifying problem areas are from the maintenance teams who record all track deviations and areas of ballast loss. Any movement of the track indicates a movement of its foundation, which will usually be instigated by some sort of ground failure. Ballast "loss" can be attributed to two major causes. Firstly, on narrow steep embankments where the ballast extends to the top of the slope loss can occur as erosion of the edge with ballast moving down slope. This problem is a function of construction surface geometry with slopes that are too steep for the materials of which they are formed to be self-supporting.

Secondly, and of much greater concern, are areas where the extent of ballast loss cannot be visually identified. This situation indicates some sort of soil failure, either by excessive settlement due to ongoing degradation of the embankment, as has occurred on many London Clay embankments, or by complete slope failure. Slope failure can be due to sliding of the surface layer on the embankments frequently remedied by the introduction of granular infilling and blankets, or deeper seated slip failure through the foundations. The latter type of failure requires extensive investigation with deep boreholes and good quality laboratory testing to determine an accurate ground model for adequate analysis and hence to facilitate the formulation of a geotechnical solution.

CONVENTIONAL INVESTIGATION SOLUTIONS

Normal intrusive site investigation techniques using cable percussive, rotary drilling and trial pitting techniques utilise moderately large plant which requires reasonable access and relatively flat exploratory hole locations. Cable percussive rigs using traditional "A" frame masts are normally towed as a trailer some 9m long by four wheel drive vehicles and erected at each location such that the mast is about 6.50m high (Fig. 1). 150mm diameter equipment and tools are traditionally used for "shallow" holes with a range of diameters in a telescopic system used if greater depths are required. However, the use of diameters greater than 250mm would normally require the use of larger, more powerful rigs. For difficult access and low headroom situations, smaller and less powerful modular rigs can be used with adjustable mast heights. These however, require shorter tools and equipment and have limited depth capability, particularly where holes have to be cased.

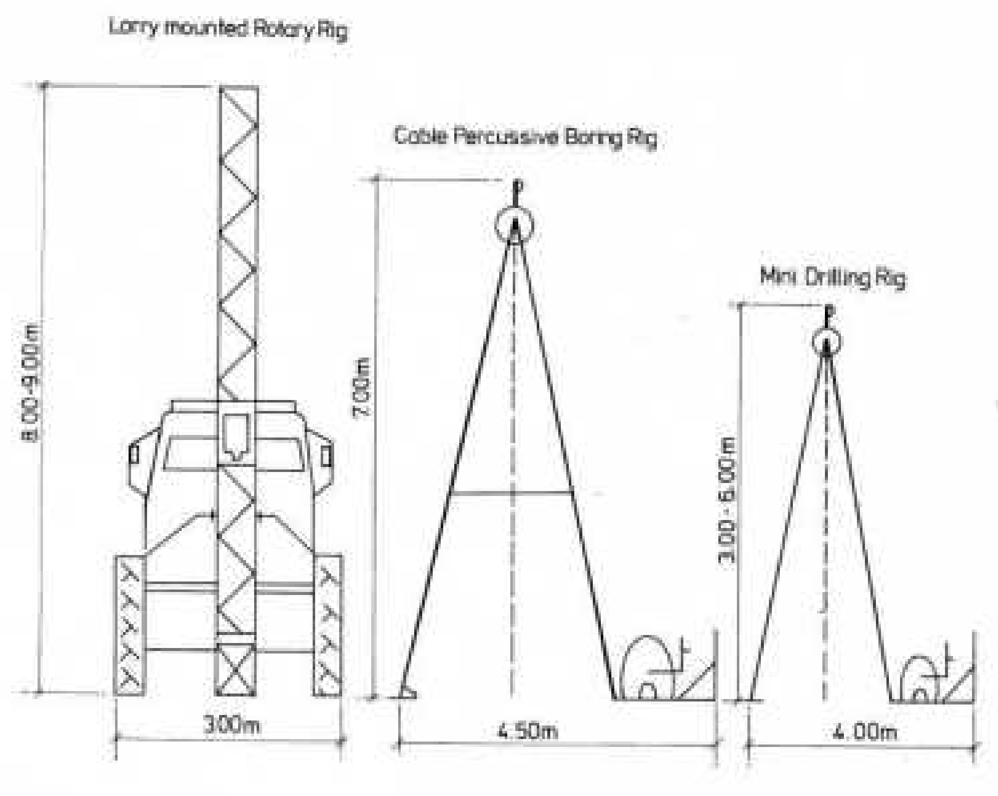

Figure 1. Relative size of Rotary, Cable Percussive and Mini Drilling Rigs

Rotary rigs are available in a great variety of sizes, power and mountings.

Probably the most common site investigation rigs are mounted on small 4x4 trucks (often ex army) and have the capability of coring to 50+m recovering cores up to 112mm diameter. Again there is a restriction on depth capability for the rig if a continuous cased hole is required or necessary where rotational torque is the limiting factor. Small compact rigs mounted on variable tracked chassis or trailers are also available for restricted access situations. Low powered rotary attachments for cable percussive rigs can also be used for proving rock to nominal depths. Rig heights can vary from about 1.50m to masts in excess of 10m for efficient rod handling in deep holes (Fig. 1).

Trial pit excavation is a rapid investigation technique but tends to cause most ground disturbance and is of limited depth capability. Any type of excavator can be used, depending on access and depth requirements. Wheeled backactors are the most versatile machines, able to access many locations. These can be used on both road and site and can excavate up to 4.50m depth. Tracked machines can be used where surface conditions are soft, slopes are to be accessed and, for larger machines, greater depths are required.

In areas of limited access mini-excavators or hand excavation can be used, but are less efficient.

In addition to being a relatively cheap and quick method of sampling across a site, trial pits also allow visual inspection of the soil structure insitu, which is most important in certain situations, for example, slip planes where slope failure is suspected.

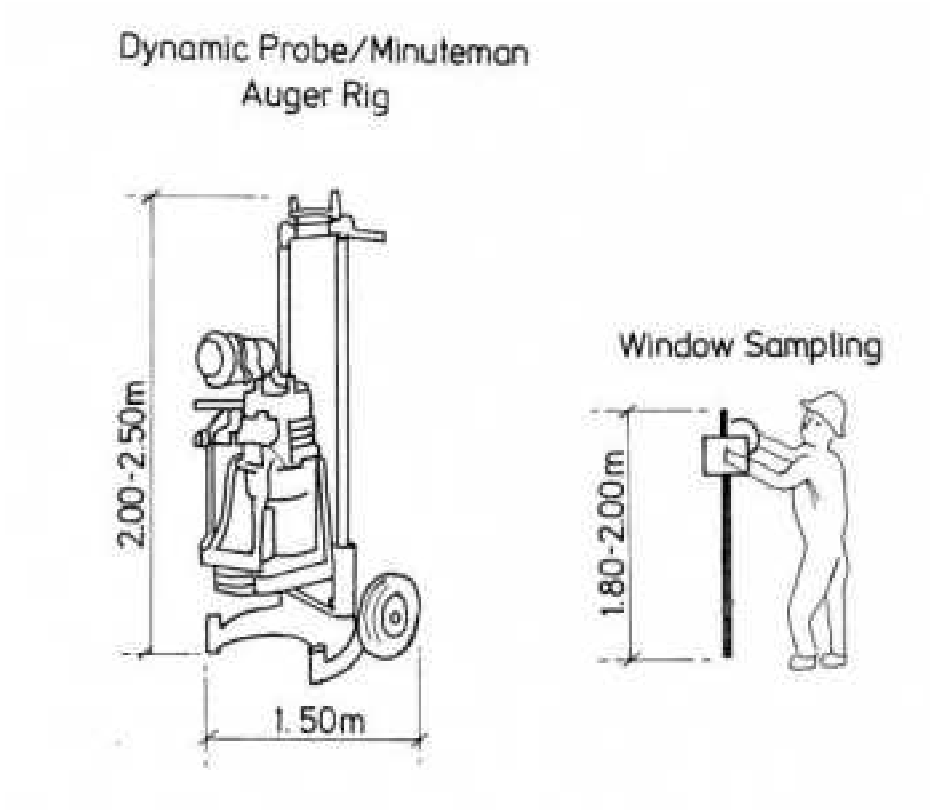

Figure 2. Relative size of Minuteman Auger/Dynamic Probe and Window Sampling Techniques

Numerous other techniques are available for sampling and insitu testing of soils and rocks and some of these will be reviewed in later sections in relation to railway investigation work (Fig. 2).

SAFETY RESTRICTIONS

Site safety in the civil engineering industry in general has been the subject of numerous guidelines and regulations in recent years, not least the CDM regulations. The danger of working on railways cannot be underestimated and Railtrack have established some of the most stringent safety procedures for work on or adjacent to railway lines.

As everyone involved in railways will be aware, method statements are required for every operation or activity and these are vigorously reviewed before approval. Appointed safety staff are required in attendance whenever activities are undertaken on railway property.

The considerations necessary for undertaking site investigation work on railway property are:-

1. Virtually all plant and equipment used is of steel construction and is therefore a hazard on electrified lines.
2. Much of the conventional plant is high or has moving parts which restrict the proximity of the plant to live tracks.
3. The requirement for possessions and isolations, when work is required in the track area.
4. Much of the railway network is on embankment or in cutting requiring special access considerations.

While much work can be undertaken in a "green zone", the green zone for conventional plant tends to be 10m or more away from the live lines in order that the possibility of plant toppling onto the line is completely removed. In some circumstances plant can be tied back to prevent toppling. The 10m restricted zone frequently takes the available investigation area outside the area of interest.

Where overhead electrification exists, any plant used must be restricted to below shoulder height and therefore only hand held or mini equipment can be used. Even where track possession and isolation of overhead lines is implemented, any plant or equipment must be restricted to less than the cable height so that any toppling would not cause damage.

Emergency investigation work and some planned work is often undertaken in possessions shared with maintenance contractors. However, this is rarely totally satisfactory, as the investigation contractor cannot establish any borehole plant on the track in case maintenance trains need access. Absolute dedicated possessions are the only way to undertake investigation or insitu testing using fixed plant.

Some difficulties also exist in the consistency of interpretation of Railtrack regulations between the regions and safety implementation staff. Thus, before any work can be planned and finally programmed, detailed method statements must be submitted and approved. A flexible approach to the methods being used must be maintained to enable an acceptable solution to be adopted.

APPROPRIATE METHODS FOR RAILWAY WORK

Virtually any method of investigation can be adopted for site investigation of railways but due consideration must be given to the practicability and resultant cost of obtaining the information. In this section the various methods of intrusive investigation will be reviewed, from most basic to expensive time consuming insitu testing. It is for the geotechnical specialist to assess the best value investigation to provide a remediation design. However, the remoteness of many sites and restricted accesses available restrict the practical extent of many investigations.

Hand Excavated Trial Pits

These can be used to investigate shallow soil conditions and also ballast formation conditions. Deeper excavations using shoring are only practical for the most critical of investigations as any excavation greater than 1.20m deep must be shored. Hand excavated pits are a pre-requisite for all other intrusive investigation techniques to clear the location for services.

Anomalous track foundation conditions determined from ground radar surveys are being investigated on certain routes by hand excavation through the ballast to expose the underlying soils. The formation level can be sampled and tested insitu using hand vane, hand penetrometer or mexicone probe. This work can be undertaken in red or green zone conditions as no fixed plant is used.

Percussion Boring

Percussion boring is becoming a very popular and economic method of sampling soils up to 10m below ground level in suitable conditions (Fig. 3). Originally the method used window samplers 1m-2m long necessitating the soil to be removed from the sampling tubes through "windows" cut in the side of the tube (Fig. 5). Developments soon followed with screw-on cutting shoes, core retaining devices and most importantly plastic liners, permitting recovered samples to be removed from the sample tube intact retaining the complete soil sequence, some semblance of soil structure and discreet samples which can be immediately sealed to retain moisture content and contamination until it reaches the laboratory.

Samplers come in a range of diameters from about 30mm to 100mm, permitting "stepped" sampling in reducing sized holes (Fig 4). The stepped sampling process reduces the problem of borehole disturbance and squeezing and also cross-contamination.

Figure 3. Window Sampling

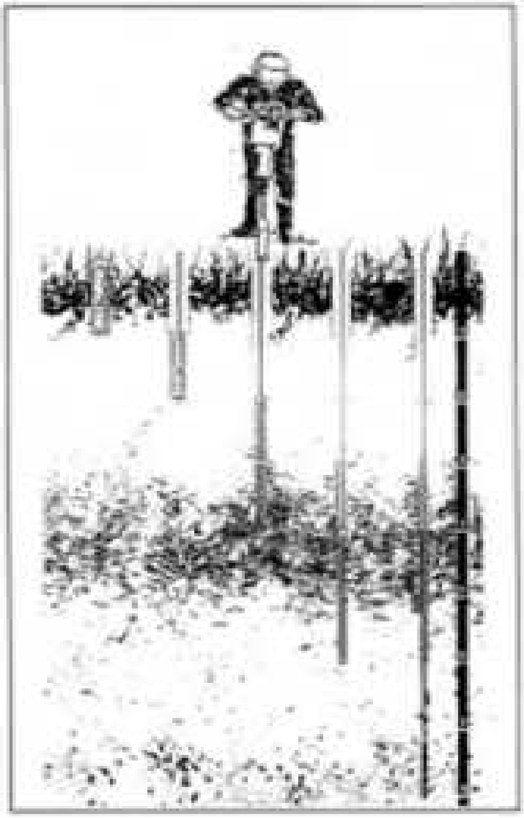

Figure 4. Stepped Window Sampling (Atlas Copco, 1999)

Figure 5. Window Sample Tubes (Carl Ham UK, 1999)

The extremely portable petrol driven hammers such as those manufactured by Cobra can be used on virtually any site regardless of accessibility. The kit can be carried by an individual and used in any headroom where the operative can function. Geotechnics has used this system on many railway projects, using wheel barrows pushed along the cess to carry the hammer, extraction jacks, samples tubes and many liners necessary for a session's uninterrupted work.

Dynamic Probing

Dynamic probing to provide resistance profiles can be obtained from a variety of different sources. The most portable system is the hand operated Mackintosh probe which uses a hand operated drop weight to drive small diameter rods and cone tip into the ground. This system also comes with a small diameter sampling system if required.

The TRL Farnell Dynamic Cone Penetrometer (DCP) was developed in conjunction with the Transport Research Laboratory (Fig. 6).

The 8 kg free fall hammer is manually lifted and dropped. The distance of penetration of the cone tip is then recorded and the cycle repeated. Continuous measurements can be made down to a depth of 1 metre (when extension rods are fitted) to a maximum recommended depth of 2 metres. Where sub-pavement layers have different strengths the boundaries can be identified and the thickness determined.

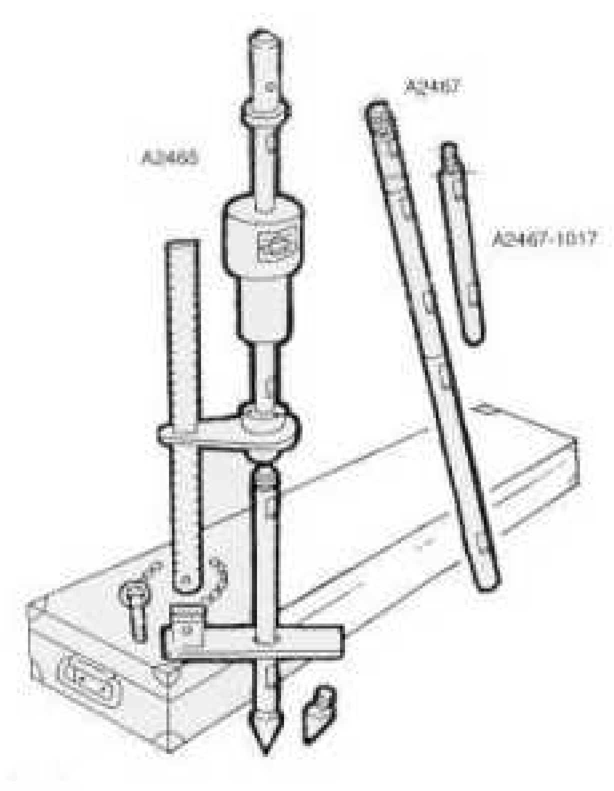

Figure 6. Farnell Dynamic Cone Penetrometer

(CNS Farnell, 1999)

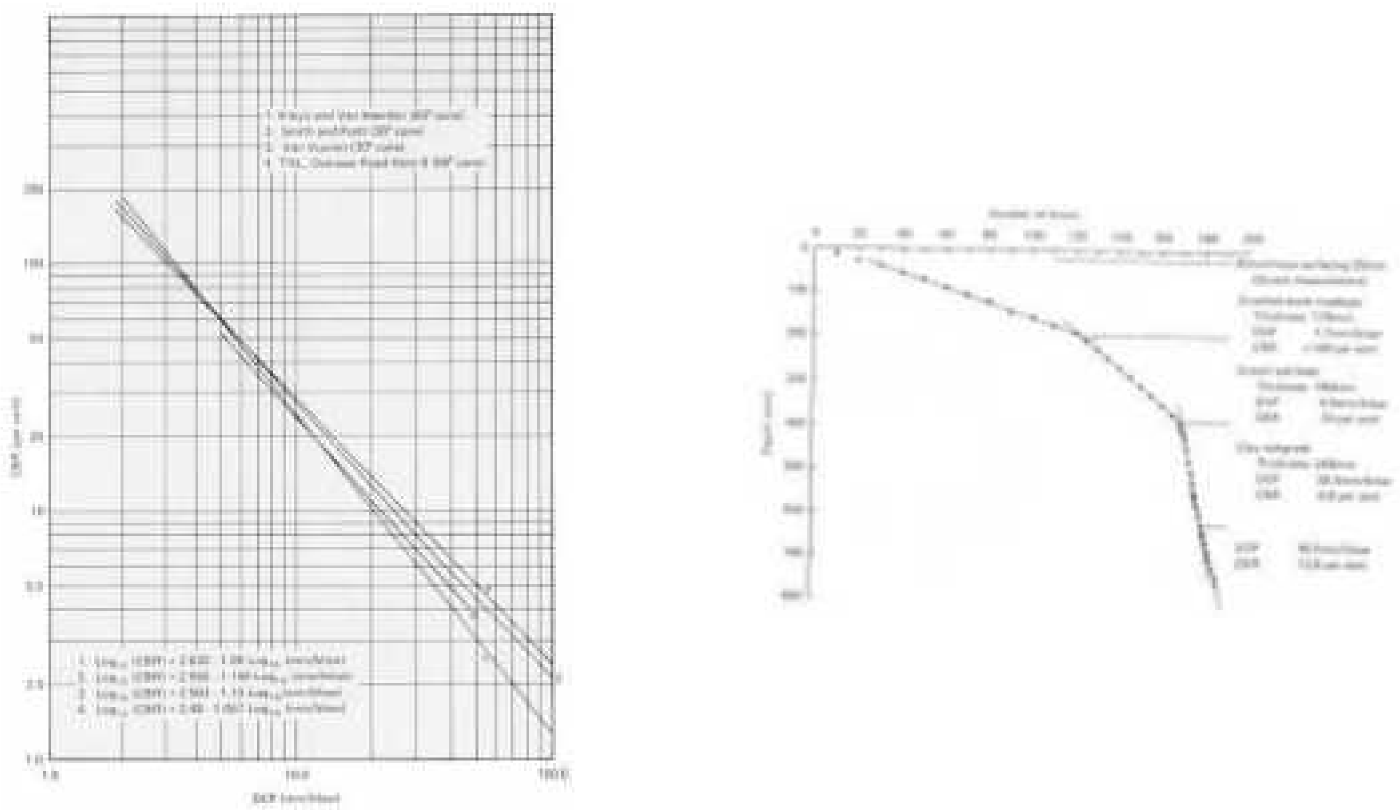

Figure 7. DCP-CBR Relationship and DCP Results Plot
(CNS Farnell, 1999)

DCP results are conveniently processed by computer and a program has been developed (TRRL (1990)) that is designed to assist with the interpretation and presentation of DCP data. CBR values for pavement formation design are then available for each stratum penetrated.

Figure 8. – Dynamic Probing, Window Sampling and Hand Pitting in use on a railway embankment

The powered dynamic probes meeting the criteria specified in BS 1377 are obviously far less portable than the hand operated probes but provide more robust equipment for deeper penetration. Pneumatic, hydraulic and mechanically driven probe rigs are available, most on a two-wheeled hand manoeuvrable chassis, land rover towed trailers or a small tracked chassis. For difficult access railway work, the small hand manoeuvred versions are normally used.

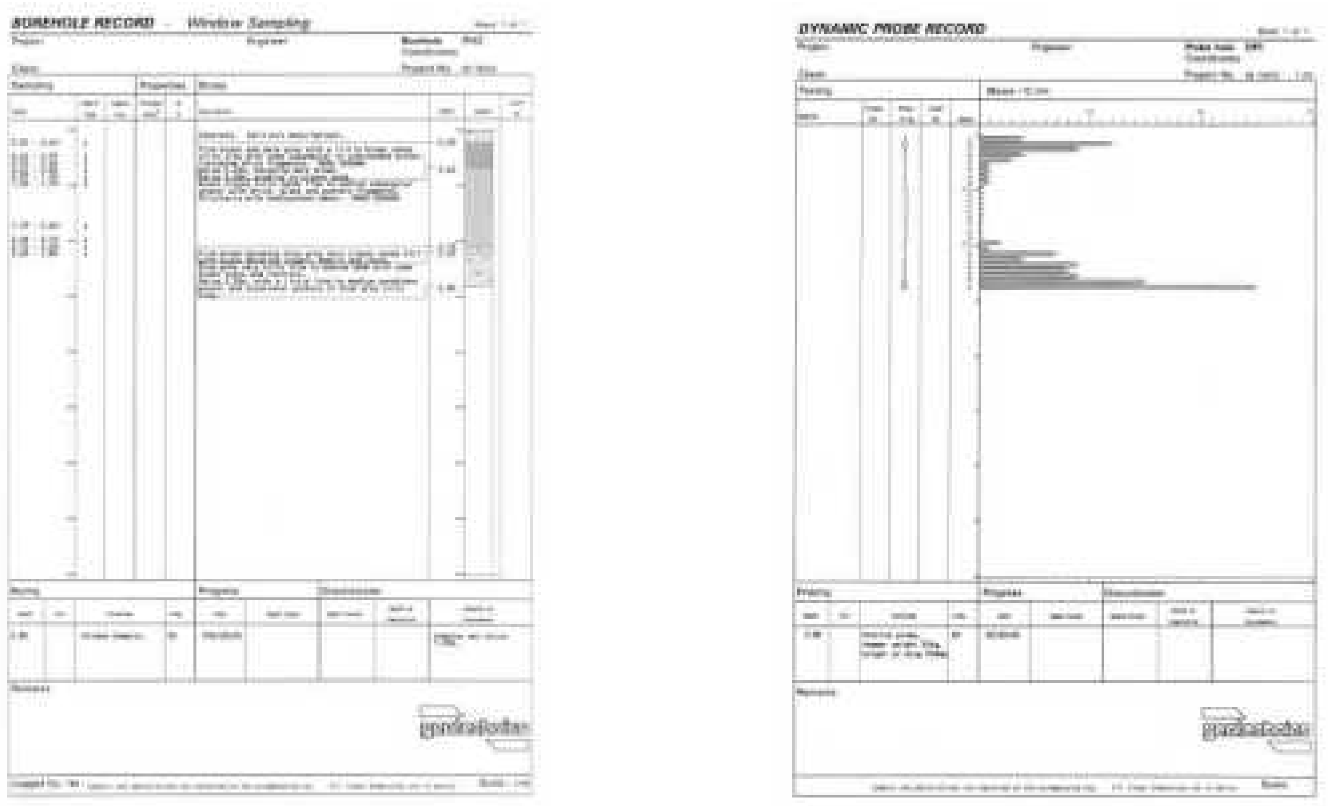

Figure 9. Correlation between a Dynamic Probe Record and a Window Sample Log

The Dynamic Probe provides a rapid and cost-effective means of assessing ground conditions, particularly on sites with difficult access, limited headroom or slopes. The wheel-mounted apparatus is only some 0.75m wide and 2m high and is powered by its own self-contained system. It can be manoeuvred by hand through doorways and up or down steps or slopes where necessary. It causes minimal surface disturbance both along access routes and at each probe location. On slopes small benches can be hand excavated to provide a level working area.

Testing is undertaken, in accordance with BS 1377 : Part 9 :1990, to provide a vertical profile of blow count for successive penetrations of 0.10m. From this profile strata sequence and engineering properties can be interpreted. The data are presented in graphical form and can be correlated with the more familiar Standard Penetration Test or used for site-specific comparisons with boreholes or trial pits. Probing depths of 5m to 10m are routinely achieved and greater depths are possible in suitable strata.

Mini Drill Rig

The Minuteman portable rotary drive rig is a similar size to the Dynamic probe rig and provides facilities for auger drilling and core drilling (Fig. 10).

The Minuteman can use solid stem and hollow stem augers and also core barrels.

Figure 10. Minuteman Auger Rig

(Mobile Drill,1999)

Geotechnics Limited has used this rig for providing uniform larger diameter holes for instrumentation installation on embankments.

Where access is somewhat easier when there are greater widths, shallower slopes or more headroom, modular cable percussive rigs or small tracked rotary rigs may be considered. However, if the use of such rigs is being considered, thought must be given to the fact that they cannot be rapidly removed from the exploratory hole location if working close to the track and the cable percussion rigs have a minimum height requirement of 3m normally meaning they cannot be used within 6m of a live line. This would usually require scaffolding to be erected on the embankment or cutting slopes with additional access and safety considerations. It would not normally be acceptable to cut relatively large benches into railway slopes to provide a level working area for the rig. Tracked machines can often be used on shallow embankments where use can be made of sleepers to level one side of the rig.

Conventional Plant

Conventional boring and drilling plant can only normally be used at the bottom of embankment slopes or the top of cuttings, away from the slope where the rig cannot topple onto the track. Static cone penetrometers, insitu pressuremeter test equipment and other more sophisticated evaluation techniques may also be considered for particular problem sites. However, where access to the sites is normally a considerable distance over fields, as access along the track is normally not possible, and extensive land damage would result from rigs, scaffold lorries and cranes traversing such areas to permit exploratory holes or test locations on embankment or cutting slopes. It is not normally practical to negotiate such access and is apparently not considered cost effective as such methods are rarely specified. However, conventional plant is quite often adopted at road bridge sites where access is available.

INSTRUMENTATION

One of the most common causes of problems in the ground, particularly where slopes are concerned, is groundwater. It is therefore most important to obtain a groundwater model and to determine its interaction with the soil model. Artesian and perched groundwater conditions can provide particularly unexpected problems if not fully assessed. For instance perched water tables, if not identified, can inundate excavations with sometimes-catastrophic effect. Similarly, artesian or sub-artesian conditions can cause delayed failures in apparently dry excavations in clay soils with the excavation base being forced upwards prior to inundation. Artesian conditions can also cause slope failures. It is therefore important to understand how any construction or remedial measures will affect the groundwater model.

There are a variety of installations in boreholes, which can be used to monitor groundwater. The simplest is a slotted standpipe with suitable granular filter surround. A standpipe piezometer with porous tip and sand filter sealed in a particular horizon can be used to monitor artesian conditions, perched water tables and normal groundwater. However, these two types of installation have rigid connections to the surface and risk damage if construction or remedial earthworks plant are to be used following installation.

Pneumatic and hydraulic piezometers utilise monitoring tips installed at the required depth with flexible monitoring tube taken to surface and subsequently in shallow trenches away from the construction area to a remote monitoring point. These types of piezometer have an improved response time and provide more accurate results, which are typically monitored by electronic readout units. However, there is a significant cost differential between these and the rigid standpipe types.

Driven steel standpipe piezometers can also be installed by hand or machine, where soil profile information is not required or when it is already known.

Ground movement can also be monitored by instrumentation. Vertical ground settlement can be monitored using magnetic extensometers placed at selected levels in boreholes or by the placement of surface monitoring installations. In either case it is necessary to have fixed reference points. For extensometers the base of the installation must be grouted into stable ground where only minor settlement is anticipated relative to the earthworks materials being monitored. For surface monitoring points remote benchmarks must be established.

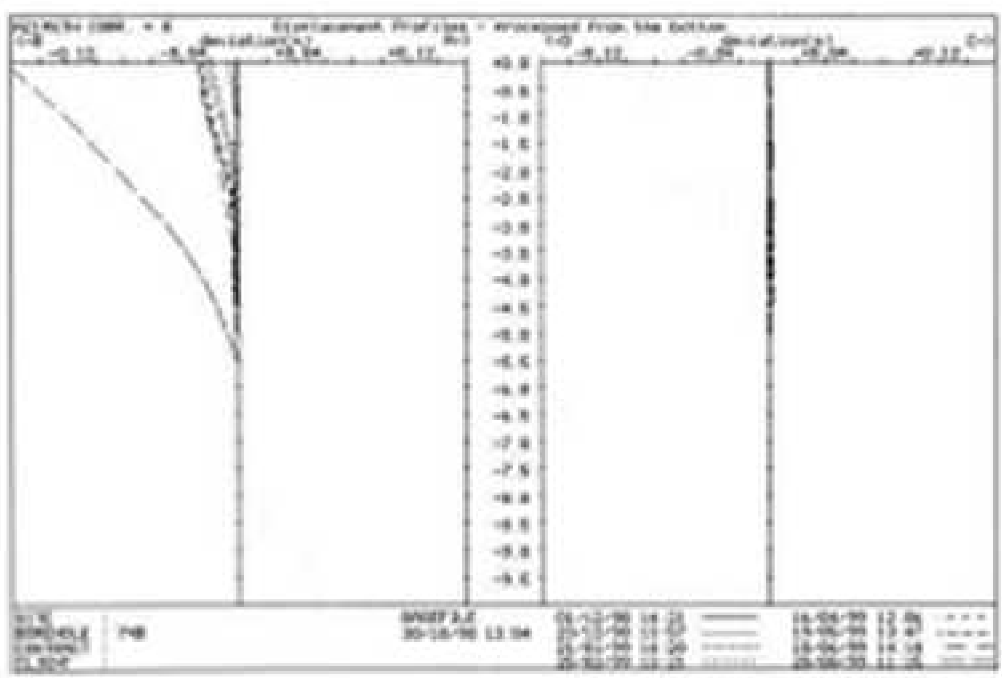

Figure 11. Inclinometer data showing sudden failure of an embankment

Failure of soil structures following construction more commonly takes the form of lateral soil movements or slips caused by shear failure within the soils. In such case it is necessary to determine the location of any failure plane. Slope failures normally start with minor movements along the failure surface(s), which may not show at the surface initially or be hidden by extensive vegetation cover (Fig. 11). Track maintenance teams may be the first to identify instability when alignment problems are observed. The identification of failure planes may be undertaken from the detailed examination of continuous undisturbed samples of the soils but this is rarely a practical option and may not reveal the actual problem strata.

The installation of slip indicators or inclinometers will provide a long term monitoring ability with ongoing observations identifying areas most at risk. Slip indicators are a relatively crude system of flexible plastic tubing installed in boreholes with sand or grout surround. A brass sounding rod linked to the surface by string or fishing line is placed in the base of the installation. Further rods or varying lengths are lowered from the ground surface. If any movement occurs the rods will fail to pass down the tube across the slip zone. The depth and extent or movement is assessed from the length of line and length of rod, which is obstructed. The base rod is pulled up the tube to identify the bottom of the movement zone. This system will only provide a qualitative assessment of movement but is low cost and can be installed in any type of borehole or probe hole, which remains open.

Figure 12. Inclinometer Equipment (Geotechnical Instruments, 2000)

Further readings are taken at regular intervals, depending on the perceived risk, so that any minor movement can be monitored. Depth, direction and vertical extent of the potential failure zone can be determined from a single installation and if multiple installations are adopted in a potential danger zone, the full extent of the potential failure can be assessed together with the likely mode of failure.

SUMMARY

Despite the considerable restrictions and problems that working on railways poses it is still possible to obtain a reasonable amount of data from which a soil ground model can be established. The investigation process is most cost effective when a phased approach is adopted and successive phases are designed based on all information and data available at the time. A Geotechnical Specialist with sufficient knowledge and experience of the problems likely to be encountered and their solution should control all work.

Phase 1 should be the Desk Study where all available data is collected and assimilated. Subsequent phases, as deemed appropriate, may include geophysical surveys, preliminary intrusive investigation, using light weight equipment with basic laboratory testing, detailed investigation, using larger or more specialist intrusive techniques and finally, observation of construction and remedial works, to confirm the ground model and make any necessary design changes as work proceeds.

The investigation process relies on the experience of geotechnical specialists to design the investigation and interpret the ground conditions particularly where the numbers of investigation points are limited. It is essential that the model is kept under constant review as data becomes available in order that the optimum cost-effective solution is achieved.

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