Site Investigation for the Effects of Vegetation on Ground Stability

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Short running title: ‘Investigating the effects of vegetation’

Abstract
The procedure for geotechnical site investigation is well established but little attention is currently given to investigating the potential of vegetation to assist with ground stability. This paper describes how routine investigation procedures may be adapted to consider the effects of the vegetation. It is recommended that the major part of the vegetation investigation is carried out, at relatively low cost, during the preliminary (desk) study phase of the investigation when there is maximum flexibility to take account of findings in the proposed design and construction.
The techniques available for investigation of the effects of vegetation are reviewed and references provided for further consideration. As for general geotechnical investigation work, it is important that a balance of effort is maintained in the vegetation investigation between a) site characterisation (defining and identifying the existing and proposed vegetation to suit the site and ground conditions), b) testing (in-situ and laboratory testing of the vegetation and root systems to provide design parameters) and c) modelling (to analyse the vegetation effects).

Key words: desk study, ground stability, in-situ and laboratory testing, site investigation, vegetation

1. Introduction

The procedures for site investigation before construction and environmental projects and the scope of necessary technical input have been defined by various guidance publications and texts (Clayton et al., 1995; Highways Agency HD22/02; Site Investigation Steering Group, 1993; Simons et al., 2002; Greenwood, 2005a). Little attention has been given during routine geotechnical investigation to the part that vegetation might play in contributing to the engineering stability of the existing site or proposed works.

Whilst the potential application of vegetation to assist stability is generally associated with slopes (Barker, 1986; Coppin and Richards, 1990; Gray and Sotir, 1995; MacNeil et al., 2001), it should be noted that vegetation also plays a part in stabilising horizontal surfaces to improve shear resistance. The penalty miss by footballer David Beckham during the European Cup finals of June 2004 (Figure 1) was claimed by Sven Goran Eriksson, the coach, to be due to the fact that 'he slipped with his foot once again because the area around the penalty spot didn't have enough grass'. The significance of ground stability for multi-million pound/euro sporting events should not be underestimated in today's economy which increasingly depends on leisure activities.

The more traditional need for applications of soil bioengineering (or eco-engineering) to sloping ground are illustrated in Figures 2 and 3 where the occurrence of shallow landslides may well have been reduced with appropriate soil bioengineering measures. The investigation of the effects of vegetation is particularly relevant to shallow slope failures, preventative works and erosion control.

2. Current procedures for geotechnical site investigation

2.1 Investigation Stages

The investigation work for most construction projects is divided into stages as illustrated in Table 1. The Geotechnical Advisor is normally appointed at the outset of the project and will ensure appropriate geotechnical input at each stage.

2.1.1 The Desk Study / Preliminary Sources Study

The desk study, sometimes referred to as the 'initial appraisal' or 'preliminary sources' study is vital for determining a preliminary understanding of the geology of the site and the likely ground behaviour. The term 'desk study' can be misleading because in addition to collection and examination of existing information, it must include a walk-over survey. The study will determine what is already known about the site and how the ground should be investigated.

Before embarking on intrusive ground investigation work, much valuable information may be readily gleaned from existing sources such as geological and Ordnance Survey maps, aerial photographs and archival material. Such documents can yield much about site conditions. The information from these sources is combined with the walkover survey to enable preparation of a geotechnical ('geohazard') plan of the site. A check list of information to be sought in a desk study is given by Perry (1996).

The desk study often represents the most cost effective element of the entire site investigation process revealing facts that cannot be discovered in any other way. The preliminary engineering concepts for the site are prepared and developed at the desk study phase based on the acquired information. The ground investigation in the field is then designed to confirm the conditions are as predicted and to provide ground information for the detailed design and project construction.

2.1.2 The Walkover Survey

The walkover survey is a detailed inspection of the site often done in stages with the initial visit for familiarisation, photography and checking of the current site conditions and with subsequent visits to confirm features noted on historical maps and photographs, etc.. Features should be sketched at an appropriate scale on a base plan for inclusion in the desk study report.

2.1.3 The Procedural Statement

The key to successful site investigation lies in the planning process. If all aspects of the investigation work are considered in advance together with necessary actions relating to the likely findings, then the outcome is likely to be satisfactory for all parties involved.

A convenient way to bring together and record the proposals for each stage of site and ground investigation is by a 'Procedural Statement' (sometimes referred to as the 'Statement of Intent' or the 'Ground Investigation Brief'). This approach was formally introduced by the Department of Transport/ Highways Agency in the 1980's and has now become widely accepted as good practice (Highways Agency HD 22/02). An example of headings and topics covered in a Procedural Statement is given in Table 2. Headings and content will change slightly for each phase of the investigation process as more information is accumulated.

The Procedural Statement is usually prepared by the Geotechnical Engineer / Advisor responsible for the work and should be agreed by all interested parties, and in particular the client, before the investigation proceeds.

The Statement encourages the designer to consider relevant aspects of the proposed investigation and to seek authority to proceed. It forms a valuable document within a quality management system and it becomes a base reference as the investigation proceeds in case changes are needed in the light of the findings.

3. Addition of the Vegetation Investigation

The proposed additional sections and notes to consider the effects of vegetation in the Procedural Statement are shown in bold italic in Table 2. This will draw the attention of the project team (and funders) to the possible application of the vegetation to assist the engineering performance. It will highlight the need for specialist consultation and help plan the necessary investigation to demonstrate the potential of the vegetation.

3.1 Suggested outline procedure for investigation of vegetation

Table 3 outlines the typical factors relating to vegetation which may be considered at each stage of the investigation. It is noted that the major part of the vegetation study can (and should) be completed at the desk study / preliminary stage.

4. Review of techniques available to help investigate the effects of vegetation

The following paragraphs briefly review the techniques which may be used for investigation of vegetation effects and provide references for further consideration of the various techniques.

4.1 Vegetation survey

The extent of a survey of existing vegetation will relate to its relevance to the planned works. There is little point in carrying out detailed surveys of existing vegetation if the proposed works require re-profiling of the ground and removal of vegetation and topsoil. On the other hand, where existing vegetation can be preserved its nature should be recorded and possible contribution to ground stability assessed. The following is recommended:-

- All trees and shrubs should be identified and locations recorded with local investigations of root extent where possible
- The general presence and nature of ground cover (grasses, ‘weeds’, etc.) should be recorded
- The maturity and vitality of the vegetation should be recorded

Where existing (or proposed planted) vegetation is to play a role in engineering stability, more detailed surveys should be carried out as suggested by Cammeraat et al. (2002). The survey is carried out by placing a suitable square grid (quadrat) over the soil and vegetation to record and monitor factors such as the seasonal variation, percentage ground cover and the determination of the mass of vegetation (biomass). The advice of a plant specialist to assist with such surveys is recommended.

4.2 Topsoil and subsoil

As the prime growing medium, the available topsoil and subsoils (upper 1.5 m) should be classified in horticultural terms so that existing suitable plants can be encouraged or new plants selected for their engineering contribution.

Consideration might be given to possible treatment of the topsoil and subsoils by aeration and/or fertiliser, to encourage the development of mycorrhizal associations and deeper, healthy root growth (Ryan and Bloniarz, 2000).

4.3 Trial pits and boreholes

Shallow trial pits, preferably hand dug, can often be put down with minimal disturbance and provide an excellent means of assessing root distribution and the nature of the topsoil and subsoil layers. As the excavation only represents a snapshot in time, the likely seasonal influences of changing moisture conditions need to be considered (Greenwood et al., 2001).

Root size and distribution may be assessed and recorded by image analysis of the trial pit wall or by manual counting using a ‘quadrat’ or square grid, typically of 100 mm squares, placed over the vertical sides or horizontal base of the pit (Greenwood et al., 2001).

Boreholes are less valuable than pits for root distribution analysis but horizontal sections through recovered core samples can provide a limited indication of root counts (Greenwood et al., 2001).

4.4 Geophysical techniques for root location

Geophysical techniques such as Ground Penetrating Radar (GPR) have been used with partial success to map tree root systems. The four fundamental factors to consider with any geophysical method are penetration, resolution, signal to noise ratio and contrast in physical properties (McCann et al., 1997). There is a trade off between resolution and penetration depth, penetration may be increased by using a lower frequency but resolution is improved by using a higher frequency (Hruska et al., 1999). However, the attenuation also depends on the conductivity of the soil, therefore, soil type and overall root depth are important factors determining the success of this method. Dobson (1995) and Hruska et al. (1999) have reported successful plan and three dimensional images of roots, but Stokes et al. (2002) reported problems with root crossover and branching, and in determining the location of roots less than 20 mm diameter.

The geophysical techniques are worthy of further consideration to supplement the physical investigations particularly as computer processing power increases to help interpret the geophysical survey results.

4.5 Moisture content determination

Moisture content is a fundamental property relating to soil strength and consolidation characteristics. Changes in moisture content will occur primarily due to seasonal effects but also due to the influence of the vegetation. Seasonal comparisons of moisture content profiles in vegetated and non vegetated areas of the site will be of assistance in considering the vegetation effects.

Physical sampling inevitably involves partial destruction of the site by trial pit or borehole and therefore can only provide a snapshot of conditions at the time of excavation. Moisture profiles at close centres (say 50 or 75 mm) on a vertical profile or as a grid around root networks can provide helpful information. The ‘moisture in the bag’ technique (Greenwood and Norris, 1999) saves time on sampling and laboratory drying procedures.

Other techniques such as time domain reflectometry (TDR) (Topp and Davis, 1985), Theta probe (Gaskin and Miller, 1996), and Neutron probe (Vickers and Morgan, 1999) permit monitoring of moisture content over extended periods by having either a permanent access tube installed for insertion of a probe or by leaving an instrument buried in the ground to allow continuous real time monitoring. Considerable success is reported with these devices (Vickers and Morgan, 1999; Greenwood et al., 2001) although caution is needed in their calibration which should preferably be done against physical moisture content determination. The remote devices generally record volumetric moisture content (volume of water divided by total volume of specimen) as compared with the gravimetric moisture content (mass of water divided by dry mass of soil specimen) which is more familiar to geotechnical engineers (BS 1377, 1990). Relating the two approaches to moisture content requires the measurement or assumption of the dry density of the soil, i.e.,

$$\text{Gravimetric moisture content} = \text{Volumetric moisture content} \times \frac{\text{Density of water}}{\text{Dry density of soil}}$$

(Greenwood et al., 2001).

4.6 Water Pressures

Effective stresses which govern the stability of soil slopes are dependent on the pore water pressures present in the soil mass. Traditional monitoring devices of standpipes and piezometers (BS5930, 1999) are valuable for general slope stability monitoring but are unlikely to detect the specific influences of the vegetation (Greenwood et al., 2001). More detailed studies of wetting fronts during rainstorm events (Vickers and Morgan, 1999) and seasonal variation in water pressures are possible by means of tensiometer installations (Greenwood et al., 2001). Tensiometers are considered to be most helpful for assessing water pressures and suctions where the effects of vegetation and other hydrological influences are to be considered in detail (Anderson et al., 1996; Greenwood et al., 2001).

4.7 Root strength

For analysis of root reinforced soil an estimate of the contribution of roots to stability is required (see '*stability modelling*'). This may be obtained directly from in-situ root pull-out tests (Norris and Greenwood, 2003) or from laboratory tests (Coppin and Richards, 1990). Again account needs to be taken of the season at which the testing is completed compared with the most critical 'wet' periods for the site.

Laboratory measurements of root tensile strengths are helpful and should provide root characterisation data to be checked against published results for the particular species (Ecoslopes manual, in prep.).

In situ shear tests can give a direct indication of the shear strength of root reinforced soil but are difficult to interpret in relation to the drained/undrained conditions and the stress distribution within the sample (Norris and Greenwood, 2000a, b; 2003; Greenwood et al., 2004).

4.8 Stability modelling

The modelling tools available for analysing the effects of vegetation need to be considered at the outset so that the investigation is designed to provide the required data.

Various methods of limit equilibrium stability analysis are available in commercial packages such as SLOPE/W (Geoslope International Ltd.). Methods based on equilibrium of hydrological forces are shown to be most reliable for estimating the factor of safety and are readily adapted to include the vegetation effects (Greenwood, 2005b). The SLIP4EX program based on Microsoft Excel, compares methods for a single slip surface and is freely available (contact: john.greenwood@ntu.ac.uk or on-line Journal of Geotechnical and Geological Engineering web site?) for initial exploration of vegetation effects (Greenwood, 2005b). Root effects may be represented by radial zones of enhanced soil properties around a single tree or by depth related zones parallel to the slope for general vegetation cover (Greenwood et al., 2003; 2004). Other models for consideration of soil-root interaction are discussed by Wu (1995, 2005) and Operstein and Frydman (2002).

When incorporating vegetation root effects, high partial factors of safety (typically around 8 - 10) are recommended to take account of the uncertainty of root distribution and anchorage lengths and the large strains necessary to generate the full tensile resistance of the root (Greenwood et al., 2003; 2004).

The power of numerical modelling by finite element or finite difference methods is such that both stress and strain and the generation of water pressures can be modelled for situations of root –soil interaction and ground water infiltration. The problem is that the setting up of accurate models and selection of appropriate parameters is not straightforward. Commercial programs such as Plaxis (Brinkgreve, 2002) and Seep/W (Geo-slope International Ltd.) are helpful, particularly for assessing the sensitivity of the analysis to the assumed parameters.

Programs such as Forest Gales (Gardiner et al., 2000) are available to assess specific problems of the vulnerability of trees to wind damage. Other numerical programs are under development to record and model root systems and include their influence in ground models, e.g. Dupuy et al. (2004).

4.9 Slope Decision Support System

One of the key objectives of the EU funded ECOSLOPES project was to provide a Slope Decision Support System (SDSS) to help practitioners to assess their slopes and select appropriate vegetation to help stabilise them. The SDSS may be trialled as a development version (Ecoslopes Manual, in prep.; Mickovski and van Beek, 2005) and it is intended that with the benefit of user feedback its scope will be confirmed to provide the necessary guidance for eco-engineering and soil bioengineering applications.

5. Discussion

The application of vegetation to assist engineering functions is not always straightforward and expectations as to what might be achieved must be realistic. However the costs are relatively low particularly at the preliminary (desk study) phase and therefore benefit/cost ratios may be high. The linking of the engineering solutions to an improved environment is a satisfactory and rewarding achievement.

Mistakes will inevitably be made and vegetation alone should not be relied on where life and property are directly at risk from resulting landslip.

As experience is gained the checklists and investigation techniques provided in this paper will be reviewed and updated. For all investigation work it has been recognised that there must be a balance of effort between the site and strata definition, the testing and the modelling (Burland, 1989). As vegetation considerations are included, this balance must be maintained with the site characterisation (defining strata, hydrological conditions and vegetation), balanced against the testing (on site and in the laboratory) and modelling (Figure 4). It is pointless carrying out detailed, sophisticated modelling if the strata, hydrology and vegetation properties are not properly defined. Equally, it is pointless doing many tests to determine vegetation characteristics and strengths if the results are not relevant to the site modelling.

6. Conclusions

Much of the assessment of the potential benefits (and dis-benefits) of vegetation can be efficiently completed at the desk study (preliminary) investigation stage and does not involve large expenditure. Furthermore, vegetation studies at the main ground investigation stage are again relatively low cost involving minimal ground intrusion.

Whilst the application of bioengineering will not be appropriate or relevant for all construction projects, the framework provided should encourage the project team to review the options for preservation or inclusion of vegetation which may enhance the engineering stability in addition to improving the landscape and environment.

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Figures

Fig.1. David Beckham misses a crucial penalty in the 2004 European Championships match against Portugal. (Robert Millward/Associated Press Web Site)

Fig 2. Shallow landslide problems blocking roads and trapping motorists in Scotland, after heavy rains in August 2004. (Times Newspapers)

Fig 3. Instability of cutting slopes on the M11 near Loughton. Adjacent vegetated areas appear more stable.

Fig 4. Balance of input into vegetation investigation work (Developed from Burland 1989)

Table 1. Stages of a geotechnical investigation (Greenwood, 2005a)

Construction Phase	**Investigation Work**
Definition of Project	Appointment of Geotechnical Advisor for advice on likely design issues
Site Selection	Preliminary Sources Study (Desk Study) to provide information on relative geotechnical merits of available sites.
Conceptual Design	Detailed Preliminary Sources Study (Desk Study) and site inspections to provide expected ground conditions and recommendations for dealing with particular geotechnical design aspects and problems. Plan Ground Investigation (Procedural Statement)
Detailed Design	Full Ground Investigation and geotechnical design. (Additional ground investigation if necessary for design changes or for problematic ground conditions)
Construction	Comparison of actual and anticipated ground conditions. Assessment of new risks (Additional ground investigation if necessary)
Performance/Maintenance	Monitoring, instrumentation, feedback reporting.

Table 2. Example content of a Procedural Statement to be prepared before the Ground Investigation phase (HD 22/02) ***(Suggested additions for vegetation investigation shown in bold italic)***

THE PROCEDURAL STATEMENT - Prepared by the responsible Geotechnical Advisor and agreed by the client and interested parties prior to each investigation phase.

1. SCHEME

Details of Scheme and any alternatives to be investigated; Key location plan.

2. OBJECTIVES

(For example) To provide information to confirm and amplify the geotechnical and geomorphological findings of the desk study as reported separately and to obtain detailed knowledge of the soils encountered and their likely behaviour and acceptability (for earthworks). To ascertain ground water conditions and location of any underground workings ***and nature of existing vegetation and potential for planting to enhance soil stability***. (Work limits to be defined).

3. SPECIAL PROBLEMS TO BE INVESTIGATED

Location of structures. Subsoil conditions below high embankments. Aquifers and likely water-bearing strata affecting the proposed works. Rock stability problems. Man-made features to be encountered. Effects on adjacent properties etc. ***Vegetation problems and benefits.***

4. EXISTING INFORMATION

List of all relevant reports and data. ***Including survey of existing vegetation and its potential contribution to stability. Review of plant suitability guidance.***

5. PROPOSED INVESTIGATION WORK

Fieldwork – Details of exploratory work proposed for specific areas with reasons for choice of investigation methods selected. Proposed sampling to match laboratory testing ***(including studies of vegetation and its effects).***

Laboratory work – Details of proposals with reasons for choice of tests and relevance to design ***(including root strength assessment).***

6. SITE AND WORKING RESTRICTIONS

Assessment of risk associated with proposals. Site safety, traffic management, difficult access, railway working, ***preservation of existing vegetation, topsoil*** etc.

7. SPECIALIST CONSULTATION

Details of specialist needed to support proposals ***(including plant specialists, bioengineers etc).***

8. PROGRAMME, COST AND CONTRACT ARRANGEMENTS

Anticipated start date, work programme, contract arrangements, cost estimates, specification and conditions of contract. Arrangements for work supervision, etc.

9. REPORTING

Responsibility for factual and interpretive reporting. Format of reports and topics to be covered ***(including assessment of existing and proposed vegetation).***

Table 3. Factors to be considered for inclusion of vegetation effects in stages of routine site investigation.

VEGETATION CONSIDERATIONS

Desk Study Phase

i) Soils

Existing Topsoil - shallow hand dug pits to provide initial information on soil and vegetation
Subsoils - likely penetration and distribution of plant roots
Proposed fill materials - possible provision of irrigation/drainage layers to encourage deep root growth

ii) Vegetation

Typical presence and distribution of vegetation (detail depends on project)
Consider use of non invasive techniques (Ground Profiling Radar) to assess root distribution.
Identification of indigenous species with potential to assist stability (recognising need for biodiversity)
Grass cover (survey by quadrats – one metre square with 100 mm grid) - Detail to be considered
Plan of vegetation types, trees, etc. across site
List uncertainties re: vegetation (i.e., root distribution, root penetration, tensile strength, pull out resistance, etc.) that may be assessed during main investigation phase

iii) General

Review vegetation influences on adjacent sites
Consider areas of proposed works which might benefit from vegetation to assist stability
Draw up schedule of site zones and information required
Check reference texts and Slope Decision Support Systems for guidance on likely benefit
Check availability of plant / seeds (liaising with specialist plant producers and landscape architect)
Carry out preliminary ground modelling and stability analysis based on assumed properties for soil, hydrology and vegetation.

Main Ground Investigation

If existing vegetation to be assessed:-

Trial Pits to :-
a) describe topsoil, depth, organic content, standard tests for topsoil classification (BS5930)
b) assess root distribution and carry out in situ pull out resistance tests
c) take samples of roots for laboratory tests on tensile strength
d) carry out in situ shear tests on root reinforced soils (larger investigations only)
e) compare moisture content profiles in vegetated and non vegetated areas due to different types of vegetation
Possible seasonal monitoring of moisture content profiles by access tube (TDR or Theta Probe technologies)

For future vegetation:-

Assess vegetation growth on adjacent sites
Assess topsoil and subsoil types available and likely vegetation types which can be supported in the region

Analysis

Stability analysis by limit equilibrium methods (numerical methods for ground modelling on larger projects) to assess the influences of the vegetation and help design additional planting and vegetation maintenance schemes
Where little or no existing vegetation is present (regraded slopes etc) analyse benefits/dis-benefits of proposed planting scheme

Construction Stage

Monitoring and protection of existing plants and topsoil
Treatment of soils to encourage deeper rooting
Topsoil /subsoil preparation and planting (in association with plant specialist and landscaper)
Review conditions on site as found against those predicted – modify design if necessary
Confirm that dependency on vegetation does not introduce inappropriate risks to property and life (If so a ‘hard’ engineering solution is essential)

Feedback /Maintenance

Report on achieved objectives of vegetation and planting and provide programme of necessary on-going maintenance inspections and actions to be taken in light of certain ‘foreseen’ events

Figure 1. David Beckham misses a crucial penalty in the 2004 European Championships match against Portugal. (Robert Millward/Associated Press Web Site)

British summer strikes again

No through road: vehicles are stranded by a sea of mud that followed 24 hours of torrential rain in central Scotland, just 48 hours after Boscastle in Cornwall was devastated by floods. Rescue helicopters winched to safety 57 travellers in Glen Ogle, north of Callander. Page 5

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Figure 2. Shallow landslide problems blocking roads and trapping motorists in Scotland, after heavy rains in August 2004. (Times Newspapers)

Figure 3. Instability of cutting slopes on the M11 near Loughton. Adjacent vegetated areas appear more stable.

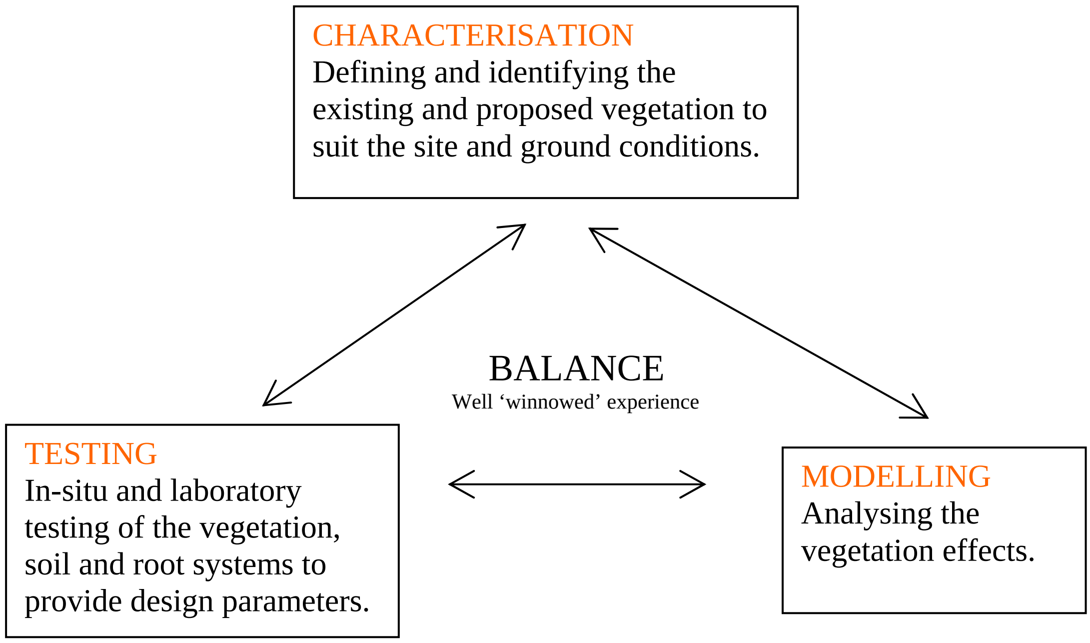

Figure 4. Balance of input into vegetation investigation work (Developed from Burland 1989).