Embankment and cut slope monitoring and analysis

Dr Derek Clarke and Dr Joel Smethurst

Introduction

- to understand the behaviour of clay slopes (natural/engineered/stabilised)
  - failure and serviceability problems
  - climate and changing climate
  - vegetation
  - design and performance of stabilisation methods

- develop models that will predict the behaviour of the slopes
  - to inform future design and maintenance
  - to identify critical actions that may have to be taken
Introduction

- we have a number of instrumented sites used to
  - monitor slope pore water pressures
  - understand vegetation effects
  - climatic conditions
  - investigate the performance of pile stabilisation structures

- we have used these site data to calibrate models of slope behaviour using
  - simulated soil moisture deficits and surpluses
  - pore water pressures

Location of field study sites

Newbury (cutting)
Watford (oak tree)
Ironbridge (River Seven valley side)
Reading (embankment)
Southend (embankment)
Hildenborough (pile stabilised embank.)
Mill Hill (pile stabilised embankment)
Grange Hill (pile stabilised cutting)
Slope at Newbury

Long term continuous monitoring of soil moisture, climate and pore water pressures in a London Clay cutting

- Neutron probe soil moisture readings
- TDR probes to measure moisture content
- Weather station
- Piezometers and tensiometers

Network Rail study sites

Embankments suffering serviceability (shrink/swell) problems

- Inclinometers (Geo-observations)
- Piezometers (Geo-observations)
- Extensometers (Geo-observations)
- Neutron probe soil moisture readings (Southampton)
- TDR probes to measure moisture content (Southampton)
- Rainfall (Southampton)
Discrete piles study sites

**Discrete pile sites**

- Strain gauges and inclinometer tubes in the piles
- Inclinometer tubes upslope and downslope of pile row
- Piezometers
- Weather stations

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Clay Research Group study site

**Watford (Aldenham) – effects of individual trees**

- Neutron probe soil moisture readings (Southampton)
- TDR probes to measure moisture content
- Weather station
- Surface level monitoring
- Resistivity measurements
- Novel treatment methods to reduce clay shrink swell
Newbury site

**Aim:**
To understand and attempt to model the physical processes that link climate > vegetation
vegetation > changes in soil moisture
changes in soil moisture > changes in pore pressure/suction

**Field work**
Instrumentation of a vegetated London Clay cut slope on the A34 by-pass
40 sensors inserted at 4 locations down the slope
Continuous monitoring since 2002

**Modelling**
Development & calibration of soil moisture deficit models
Slope modelling work using FLAC

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**Newbury site - background**

London Clay cut slope on the A34 near Newbury, 7.5m high, 16° slope

Instrumented section of slope

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Newbury - instrumentation

Instruments are installed in 4 groups

Newbury site – Vegetation changes between summer-winter

09 May 03 09 July 03 10 Sept 03 24 Oct 03
Newbury – measurement of volumetric moisture content

TDR ThetaProbes
- Used to monitor soil moisture content
- Inserted at 30 cm intervals in top 2 metres of the soil profile
- Small response zone
- Continuous data-logged readings

Neutron Probe
- Lowered down access tubes during visits to site
- Measures moisture content of football size zone of soil

Newbury – measurement of suction

Vibrating wire piezometers

Flushable water filled tensiometers in top 1.5m of the soil profile

Indirect estimates of suction near the soil surface made using Equitensiometers. These consists of a TDR probe embedded in a ceramic with known SWCC. Readings up to 1500Pa possible but calibration is difficult.
Newbury – climate and hydrological monitoring

Two climate stations used to measure
- Wind speed and direction
- Temperature and humidity
- Solar radiation

Above data used to estimate potential evapotranspiration
Using the Penman – Montieth equation
- Rainfall

Runoff collection area

Cut-off trench to measure runoff and interflow

Newbury – measured moisture contents in weathered material 2003-2006
Newbury – changes in volumetric moisture content – in weathered clay

Seasonal change in moisture content over top 1.25m depth of soil

Newbury – changes in volumetric moisture content – in cutting

Seasonal change in moisture content over top 0.8 m depth of soil
Newbury – soil water balance

Simple 1-D soil moisture balance model

Rainfall and ET

Soil moisture deficit (SMD) = amount of water required to recharge the profile

Runoff

(Runoff only occurs at field capacity)

Assume that the major moisture changes occur only in the rooting zone

At Newbury = 0.8m to 1.2m depth

Draw up of water from below the major rooting zone

Newbury – estimated potential evapotranspiration (Penman – Montieth)

Daily ETo mm/day A34 solarimeter

Monthly ETo mm/day XLS solarimeter

Monthly ETo mm/d Soton 1963-90

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Newbury – soil water balance

Total depth of available water in the rooting zone = 144 mm

RAW = 58 mm
TAW = 144 mm

Plants can readily access the initial ~40% of the water in profile

Actual ET = full Potential ET

The plants become stressed and find it harder to remove the remaining water:

Actual ET = Potential ET x f(SMD)

Draw up of water from below the major rooting zone

Max. draw up from measured summer suction gradient at Newbury

= 0.04 mm/day = negligible

Newbury – estimated soil moisture deficit 2003

Rainfall

Modelled Soil Moisture Deficit

Total available water (TAW) = 144 mm

Readily available water (RAW) = 58 mm

Actual ET < Potential ET
Newbury – estimated SMD and measured drying

Link climate and vegetation with changes in soil moisture

Newbury – FLAC model

Vegetation and climate applied through a series of flow boundaries built into surface ‘rooting zone’
Newbury - FLAC pore water pressures

FLAC pore water pressures at C location, 2003

Modelling London Clay slopes (grass cover) with historical climate data

We have shown that the measured soil moisture changes match the modelled Soil Moisture Deficit

SMD is dependent on climate and vegetation

Historical climate data is available for Southern England at various sites going back to 1885 (Oxford), 1895 (Southampton).

The climate data sets contain rainfall and data to estimate Potential Evapotranspiration. These were used to run the soil moisture deficit models from 1885-1990

Additionally we have used the BETWIXT future climate data sets to simulate SMD’s from 2010-2100
Simulated daily soil moisture deficits 1895-2100 (London)

Grass cover, TAW = 180 mm, RAW = 90 mm
Betwixt medium high scenario, London Heathrow

Long term modelling of maximum summer Soil Moisture Deficit

Grass cover, TAW = 180 mm, RAW = 90 mm
Betwixt medium high scenario, London Heathrow
Increased stress on vegetation: Number of days SMD > RAW

Long term modelling – Excess rainfall that becomes Runoff
Modelling London Clay behaviour

Pattern shows
- increase in maximum Soil Moisture Deficits in summer
- increase in summer drought
- higher frequency of dry winters when soil does not re-wet

Implications
- greater clay shrinkage for longer periods in summer
- shrink-swell cycles will increase in magnitude
- vegetation is likely to die off or change to other (semi arid) plants
- vegetation cover may decrease (exposure to surface erosion in winter)
- winter runoff reduces (however storminess is not accounted for)
Newbury – measured pore water pressures (kPa) 1.0 m – 2.5m

Newbury – measured pore water pressures near the surface (kPa)
Newbury – envelope of pore water pressure changes

Newbury site – London Clay properties

Soil Water Characteristic Curve (SWCC)

Permeability: Triaxial ~ 1 x 10^{-10} m/s; field (bail tests) ~ 1 x 10^{-8} m/s

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Newbury - moisture contents

![Graph showing volumetric moisture content and depth from ground surface]

- Link measured pore water pressures with measured moisture contents

Newbury – developing models to predict soil moisture deficit and pore water pressures

The long run of observed data has provided information on soil moisture and pore water pressure

- in wintertime
- in summer time

and shows behaviour in

- a very wet winter (2002-03)
- a typical “damp” summer (2004)
- a typical “dry” summers (2005)
- an exceptionally dry summer (2003)

We have developed soil moisture deficit models (linked to climate) and we can use historical climate data sets to estimate the likely behaviour of the site over many years

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