ACHILLES

An EPSRC Programme Grant

READING GUIDE 3:
Asset scale deterioration

ADDRESSING INFRASTRUCTURE'S ACHILLES HEEL

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Introduction

The deterioration of earthworks reduces their serviceable performance and increases the likelihood of instability. This can have significant impacts on the safe and reliable operation of the transportation networks that they support. These deterioration processes are weather-driven and may lead to failure many years after construction even in the absence of increased mechanical loads. Evidence also indicates that climate change will increase rates of asset deterioration and reduce time to failure. This document summarises the key conclusions on asset deterioration drawn from the ACHILLES body of work. A more detailed overview of the ACHILLES concept can be found in *Reading Guide 1* [1], the project website (achilles-grant.org.uk), and the following papers: [2,3].

Our main outcomes related to asset scale deterioration and its effects

Observations from instrumented UK field sites demonstrate weather-driven deterioration processes have significant effect on the hydrological properties of *in situ* soil in cut slopes and clay fill embankments, particularly at the near-surface. These changes are driven by micro- and macro- structural changes in the soil due to weather-driven wetting and drying cycles.

Permeability can vary by up to 5 orders of magnitude within the top 0.5 m across the slope surface

This variability is shown by our investigations of near-surface permeability changes [4]. Permeability is a key material property that controls the way in which different earthwork types respond to seasonal weather cycles and extreme weather. Within a relatively short time period after construction (approximately 15 to 20 years) these cycles can develop a near-surface "weathered" zone with increased permeability.

Repeated wetting and drying causes irreversible soil deterioration

Repeated wetting and drying causes irreversible soil deterioration, changing the water retention capacity, the magnitude of effective stress cycles and the soil's ability to sustain pore suctions - see *Reading Guide 2* [5] and ref. [6]. The occurrence and aperture of desiccation cracks on slope surfaces increase during drying periods, increasing infiltration capacity. The magnitude of seasonal shrink-swell movements in clay slopes is affected by the pore pressure cycle size (see examples in [3]) and are influenced by the type of vegetation present. Desiccation cracks in densely grassed slopes are long-term features, reoccurring in the same location annually [7].

The processes described above along with inherent heterogeneity can lead to significant variability within the materials forming the slopes which has been documented by ACHILLES research, including the spatial variability of high plasticity clays [8].

Deterioration of cut slopes is a function of excess pore pressure dissipation following excavation and near-surface downslope seasonal ratcheting

ACHILLES carried out a comprehensive programme of numerical modelling of long-term, weather and climate-driven deterioration of cut slopes in high plasticity, over-consolidated stiff clays [9, 10, 11]. This has shown that pore pressure dissipation dominates the deterioration in strength during the early and mid-life of the slope (approx. 60 to 70 years). Shallow ratchetting, causing strain softening, becomes increasingly important during the later stages of the life of the slope (>70 years).

Wetter-than-average years lead to larger downslope movements in cut slopes

The ACHILLES programme of numerical modelling of cut slopes has also shown that the magnitude of the annual deformation cycle is influenced by seasonal antecedence with wetter than average years (typically those with wetter summers, and wetter than average winters) leading to larger downslope movements (see Figure 1).

The magnitude of pore pressure cycles and the depth below surface to which they extend is a function of the level of development of the near-surface zone of increased permeability described in the field evidence section.

In otherwise apparently stable slopes, the depth to the critical failure surface can decrease over time due to the deterioration of the near-surface driven by seasonal ratchetting [10,11], increasing the risk of shallow translational failures over time. This behaviour has been seen to initiate at the slope toe in models and is illustrated in *Reading Guide 7* [12].

Prolonged wet periods cause increased annual slope movements in embankments

ACHILLES developed models of an intermediate plasticity silty clay embankment that were subjected to field monitored weather data. Pore pressures, water contents, and slope deformations were recorded [13]. The ACHILLES research shows that prolonged wet periods caused increased annual slope movements when compared to more typical years as also seen for the cut slope models in high plasticity clays.

Simulations must be validated with field observations. Field observations of near-surface volumetric changes and the resultant changes in the water retention behaviour and permeability needed to be reproduced to accurately capture the slope hydrological behaviour.

The deterioration seen in the cut slopes and embankment models along with that from field and laboratory studies has also informed suggestions for rapid assessment of asset condition. This is discussed in *Reading Guide 4* [14].

Future climate change will affect seasonal pore water pressure cycles in cut slopes

Numerical modelling [9] has shown that climate change projections from the UKCP09 high emissions scenario for the south of the UK will lead to increased rates of deterioration in cut slopes excavated in high plasticity clays when compared to the control climate data. Future climate change will increase the magnitude of seasonal pore water pressure cycles in cut slopes, when compared to the control (present) climate.

This increased cycle size for the future climate leads to more rapid slope deterioration and decreases time to failure. The failure time of individual slopes for common strength, stiffness and rate of strain softening is influenced by the soil permeability, with lower permeability leading to increased time to slope failure.

Similar behaviour to that for UKCP09 is seen when considering the UKCP18 high emissions data (RCP8.5) for the south of the UK. Deterioration rates in high plasticity clays are seen to approximately double when comparing UKCP09 present climate data to the range of potential future scenarios projected by the UKCP18 regional climate dataset (see Figure 2).

The time-to-failure is about half that of present/control climate conditions for future climate change

Median time to failure (MTTF) was approximately halved when future climate change was considered, compared to present / control climate data. The variability of the UKCP18 PPEs (perturbed parameter ensembles) led to a range of failure times that were plus or minus 10 years from the median time to failure.

Future climate change will accelerate the time to failure for both intermediate and high plasticity clay slopes

Modelling was undertaken on cut slopes at a range of geometries, excavated in overconsolidated intermediate plasticity weathered mudstones located in the northwest of England using the UKCP18 global climate model high emissions (RCP8.5) dataset for the area around Greater Manchester. This study found that future climate change will accelerate the time to failure for lower plasticity material similar to the behaviour seen in models of high plasticity clay slopes. Slopes subjected to control climate data were stable beyond 125 years from excavation, however when the future climate was considered, failures occurred between 65 and 85 years after excavation was completed.

The critical failure surface geometry is a function of slope angle

This modelling of cut slopes also showed that in the intermediate plasticity materials, slopes steeper than 1V in 2.5H underwent deeper seated rotational failures; whereas slopes of 1V in 3H or less steep, underwent shallow translational slides. It is suggested that the shallower, more superficial failures in slopes less steep than 1V in 2.5H will be easier to repair than the deeper-seated rotational failures seen in steeper slopes.

Cut slopes constructed in intermediate plasticity clays will be less vulnerable to future climate change than those in high plasticity clays

This modelling of cut slopes also showed that due to the higher residual strength of the intermediate plasticity material, the cut slopes excavated within it were more inherently stable than those excavated into the higher plasticity material. Therefore, cut slopes constructed in intermediate plasticity clays will be less vulnerable to future climate change than those in high plasticity clays.

Further implications of the above for slope design are discussed in *Reading Guide 5* [15] and the effect of various geotechnical interventions on rates of deterioration and time to failure is discussed in *Reading Guide 7* [12].

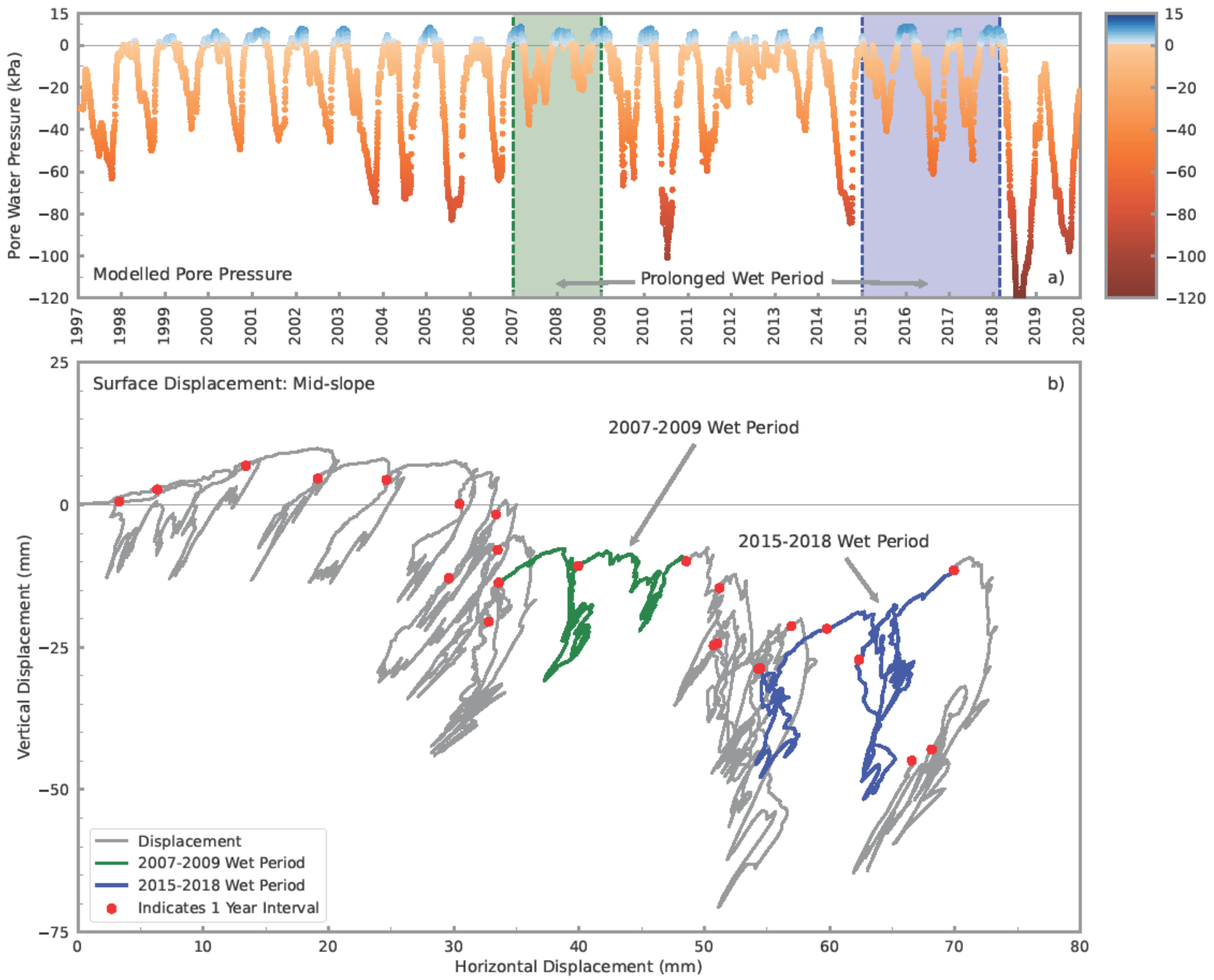

Figure 1: Effect of wet years on a) typical pore pressures near the toe of a cut slope and b) on slope ratchetting and near-surface downslope movements (adapted from [10]).

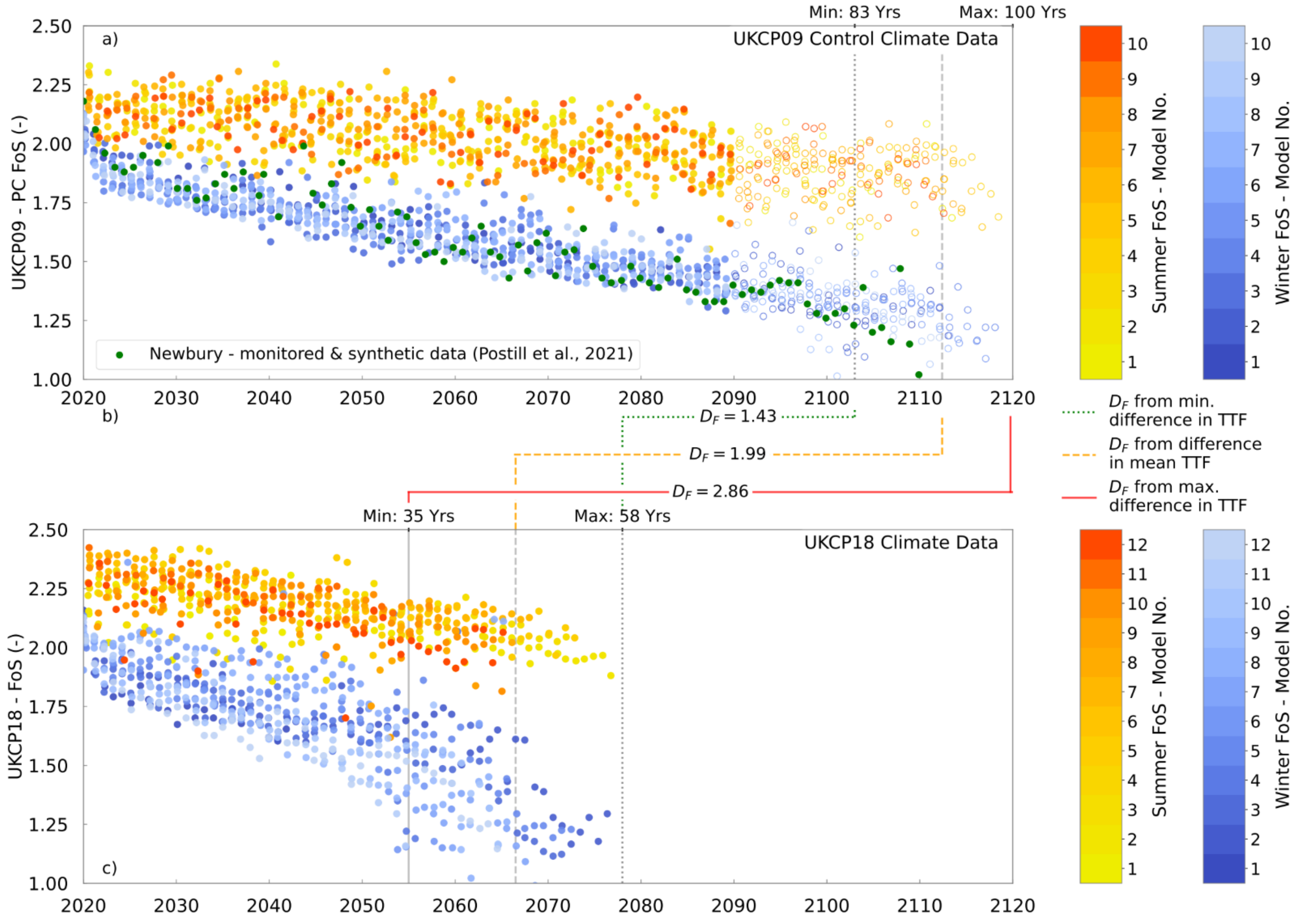

Figure 2: a) UKCP09 control (no-change) climate-driven factor of safety (FoS) deterioration curves; b) deterioration factors, D_f, calculated for the high plasticity clay cut slope numerical models from time to failure (TTF); c) FoS deterioration curves driven by the 12 UKCP18 RCP8.5 regional climate model perturbed parameter ensembles (future climate change). [16]

Further reading

Please also refer the other ACHILLES reading guides where you can find out more about what we have achieved. *Reading Guide 1* explains the context of the ACHILLES Programme Grant. *Reading Guide 2* describes how we have achieved a deeper understanding of deterioration affecting the clay materials that we focused on. *Reading Guide 4* outlines the ways in which we can assess the condition of our long linear geotechnical assets. *Reading Guide 5* provides an overview of the design tools that ACHILLES has developed. *Reading Guide 6* explains how ACHILLES sees data analytics playing a role in addressing deterioration of long-linear geotechnical assets. *Reading Guide 7* discusses the complexities of the business case of timely intervention and mitigation.

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The ACHILLES Reading Guide Series

1. The ACHILLES concept
2. A deeper understanding of deterioration of engineered soils
3. **Asset scale deterioration**
4. Asset condition assessment
5. Design considerations for clay earthworks
6. The role of data analytics in decision-making
7. Intervention strategies and business case

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