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TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY
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Climate change impacts on geotechnical infrastructure

Impacts du changement climatique sur les infrastructures géotechniques

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ABSTRACT: When undertaking designs for developments and infrastructure, geotechnical engineers now need to account for uncertainty due to climate change. For many years engineers have designed considering historical precedent, such as rare long-term flood events. Now, however, we have to accept these may be more frequent. In other areas climate change may result in periods of long duration drought with less frequent, but higher intensity, rainfall. These effects mean that geotechnical engineers must now consider different conditions which take account of a constantly changing environment over the lifetime of the structure. Geotechnical engineers must also be careful in material selection in order to achieve a required design life when ultimately, the conditions encountered now and are designed for, will change. This paper discusses these issues and how geotechnical engineers can take account of climate change in their designs.

RÉSUMÉ: Lorsqu'ils entreprennent la conception d'aménagements et d'infrastructures, les ingénieurs géotechniques doivent désormais tenir compte de l'incertitude due au changement climatique. Depuis de nombreuses années, les ingénieurs conçoivent en tenant compte des précédents historiques, tels que les rares inondations à long terme. Aujourd'hui, cependant, nous devons accepter que ces phénomènes soient peut-être plus fréquents. Dans d'autres régions, le changement climatique peut entraîner des périodes de sécheresse de longue durée accompagnées de précipitations moins fréquentes mais de plus forte intensité. Ces effets obligent désormais les ingénieurs géotechniques à considérer différentes conditions qui tiennent compte d'un environnement en constante évolution tout au long de la durée de vie de l'ouvrage. Les ingénieurs géotechniciens doivent également être prudents dans la sélection des matériaux afin d'atteindre une durée de vie de conception requise lorsqu'en fin de compte, les conditions rencontrées actuellement et pour lesquelles elles sont conçues changeront. Cet article aborde ces questions et comment les ingénieurs géotechniques peuvent prendre en compte le changement climatique dans leurs conceptions.

Keywords: Climate change; risk.

1 INTRODUCTION

In Queensland, Australia during the winter of 2022 the dry season was anything but dry. In both Queensland and the southern state of New South Wales in 2022 they were areas of flooding and in some cases repetitive flooding. At the time of writing, at the start of the 2023 – 2024 summer we are now seeing the first bush fires in Queensland. With historical global temperature records falling year after year, and weather patterns changing, it must be asked whether the basis of design for a lot of the infrastructure we build today – which is derived from historical precedent - will be relevant over the lifetime of that infrastructure.

With a constantly evolving climate, we need to consider whether our codes, standards and specifications are fit for purpose and ask how this uncertainty is going to be managed in the future.

2 GEOTECHNICAL RISKS

Geotechnical failures typically occur due to a small number of reasons:

- design – the structure is analysed incorrectly, or the design fails to account for the likely ground or loading conditions during the life of the structure
- construction – slopes are cut too steep, ground support may not be installed in time, or the incorrect materials are used
- loading changes – unforeseen changes in loading are not uncommon. Examples include: higher groundwater levels due to extreme rainfall; a new structure applying an additional

load; or, new construction such as excavation in front of a retaining wall
- change of material properties – these could include conditions such as erosion or shrink-swell

How these types of failure are impacted by climate change is discussed in the following sections.

3 CLIMATE IMPACTS AND RISKS

Geotechnical structures are typically sensitive the environment they are in. For example, groundwater levels and surface water flows impact most inground structures and earthworks.

Climate change impacts can be divided into two major groupings:

- precipitation - extreme rain, storm and floods
- increasing temperature - drought and wildfire

However, there are obvious overlaps between the two groupings. For example, hurricanes are caused by elevated sea temperatures and can result in increased precipitation and flooding (due to storm surges).

A summary of potential impacts of climate change on geotechnical structures is provided in Table 1 and examples of impacts on an earth embankment is shown on Figure 1.

3.1 Precipitation

Extreme precipitation is often associated with storms and hurricanes (cyclones) which are of relatively short duration, but high intensity, or from weather systems that continue deposit rain over a number of days or even weeks.

In general, it would be anticipated that increasing precipitation (based on Varallyay, 1990) will result in:

- surface runoff in sloping areas, especially if little or sparse vegetation is present, and the water carrying capacity of the soil is limited
- higher water infiltration and storage, recharging of the groundwater, where water carrying capacity of the soil is not limited

The consequences include an increase in instability of retaining walls and slopes (natural and manmade) which are often observed in the form of landslides (Bracko et al., 2022; The Earthworks Management Task Force, 2021; Toll, 2001).

Increased surface water flows can overwhelm existing drainage systems increasing erosion and making slopes susceptible to infiltration and surficial instability in following rain events. In addition, this could block culverts and undermine structural foundations.

The impact of rising groundwater may also bring naturally occurring sulfates and chlorides from their dry states into solution causing faster deterioration of substructures (Mallick et al., 1989). Alternatively, lowering groundwater tables expose timber piles to aerobic conditions and subject them to biodegradation (Toll et al., 2012).

Short or long-term rises of groundwater can impact foundations and basements reducing bearing capacity, causing uplift or increasing seepage. For retaining walls, increased water pressures will be observed.

3.2 Increasing temperature

Increasing temperatures can influence soils and ground conditions – drying out soils and if long-term can cause a reduction in the groundwater level. In general, it would be anticipated that increasing temperature (based on Varallyay, 1990) will result in:

- decreasing surface runoff, infiltration and recharging of the groundwater, if accompanied by low precipitation
- modification of the extent and depth of permafrost, resulting in increasing groundwater storage and movement

Lower groundwater levels may adversely impact the settlement of structures and increase loads on piles due to negative skin friction (Toll et al., 2012) or through by reducing buoyancy. Areas of karst geology, where the ground is supported by flooded caverns may be severely impacted by lowering groundwater levels resulting in collapse and sinkholes forming (Chen et al., 2021; He et al., 2022; Toll et al., 2012).

In northern latitudes rising temperatures have had the greatest impact on ground conditions. It is typical for settlements in these areas to be built on permafrost - the situation where groundwater near the surface is permanently frozen. As temperatures have increased, whole settlements - and their road accesses - are being flooded due to the recent release of groundwater making the areas marshy or swamp like. Even those areas not as significantly impacted, are facing buildings sinking due to lower bearing capacities. Slopes are also failing due to the release of groundwater.

In Alaska there are long-term concerns about the impact to infrastructure – roads, rail and pipelines – as well as former defence bases where melting permafrost may lead to contamination spread (U.S. Arctic Research Commission Permafrost Task Force, 2003).

Recent examples of hot weather influencing ground conditions are in the UK where the hot weather has resulted in an increase in the number of subsidence claims and have resulted in a number of large-scale coastal rock falls (Menteth, 2022).

Table 1. Summary of potential impacts on geotechnical infrastructure due to climate change (after Bridges, 2023; based on Vardon, 2015).

Climate change feature	Potential impact on geotechnical structure	Potential failure mode
Existing infrastructure		
Increased temperature (incl. fire)	Reduction of vegetation Hydrophobic soil	Erosion, slope stability Erosion
Decreased precipitation (drought)	Soil desiccation Soil shrinkage Reduction of vegetation / soil erosion Lower groundwater level	Piping, internal erosion, slope stability Piping, subsidence Piping, slope stability Overloaded piles, serviceability failure
Increased mean precipitation	Some soil erosion / loss of soil quality Change in water table leading to instability	Erosion, piping Slope stability
Intense precipitation	Significant soil erosion Rapid soil wetting, highly dynamic pore pressure changes potentially Flooding	Piping, slope stability Slope stability Piping, internal erosion, slope stability
Freeze/thaw cycles (incl. reduced permafrost)	Loss of soil structure Expansion of rock joints	Slope stability, bearing capacity, serviceability failure Rockfall
New infrastructure		
Drought	Reduction of moisture content of fill (compaction more difficult) and mixing of fill with water is expensive	Cost, serviceability failure
Increased precipitation / intense precipitation	Collapsing of some fill material due to wetting	Slope stability, serviceability failure

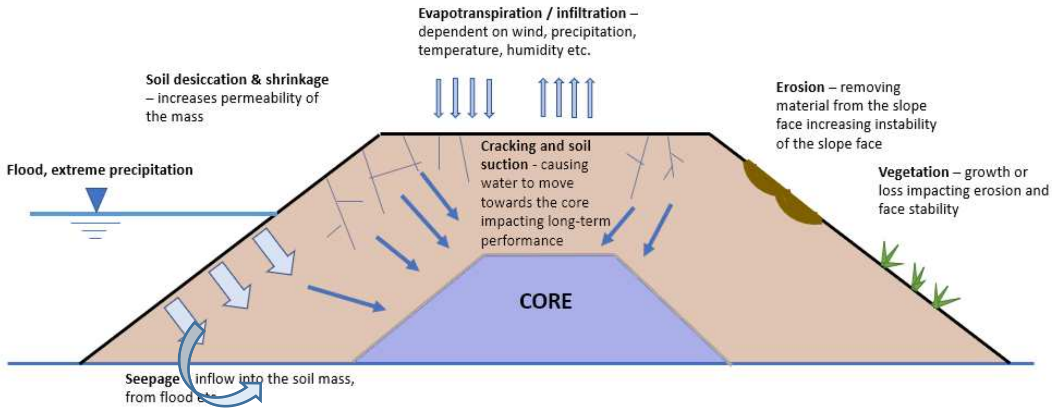

Figure 1. Influence of climate impacts on soil moisture and erosion (NTS) (based on Bridges, 2023; Vardon, 2015).

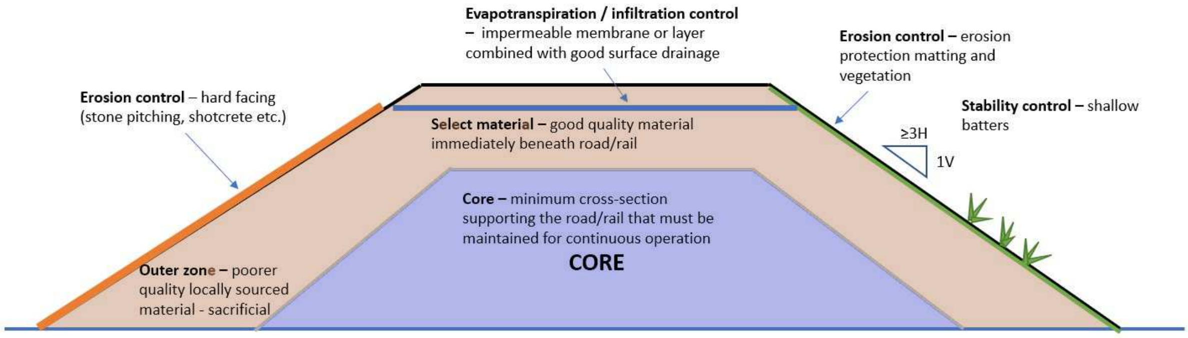

Figure 2. Influence of climate impacts on soil moisture and erosion (NTS) (Bridges, 2023).

Hot, dry conditions can also have an impact on forest or wildfires. Apart from destroying vegetation which can increase erosion, soils become hydrophobic in the period immediately after a fire, which can also increase the susceptibility to erosion (Movasat and Tomac, 2021).

4 ENGINEERED SOLUTIONS

There are a number of solutions that can be adopted to provide long-term performance of geotechnical structures. For example, for embankments some options include (Figure 2):

- wider and shallower embankment shoulders
- soft erosion protection for shallower slope batters and harder protections for steeper batters
- surface and interior drainage
- higher embankment heights to keep the infrastructure above flood levels

For cut slopes erosion protection and surface drainage are primary elements to address, combined with sub-horizontal drains to reduce groundwater levels.

Pile foundation design need to consider additional loads due to rising or falling groundwater levels. It is more difficult to address all the possible scenarios for shallow foundations, such as higher groundwater levels impacting bearing capacity) and this may lead to the adoption of more piled foundations in future.

5 CONCLUSIONS

Codes, standards and specifications are retrospective by nature and climate change impact challenges the geotechnical engineer to develop solutions not based on precedence but to think through the possible environmental conditions their structures will face.

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