Collaboration for Environmental Evidence

Systematic Review No. 90

The impact of changes in the water table and soil moisture on structural stability of buildings and foundation systems

Draft Review Protocol

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Cover Sheet

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1. Background

The IPCC 4th Assessment Report (IPCC, 2007) provides evidence of global warming as a result of increased greenhouse gas production since the start of industrialisation in 1750. The implications of this, as the report states, are: "Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century". This represents the consensus view of many climate scientists, although, of course, there are continuing debates concerning the evidence and conclusions at both scientific and political levels.

In the last decade we have seen the occurrence of extreme climate events. In the UK, the winter of 2000/1 was the wettest on record; the period May-July 2007 was the wettest for 250 years (leading to extensive flooding in Gloucestershire, Worcestershire and Yorkshire); flooding in Cumbria in 2009 was reported as the worst for 1000 years. Whether or not these extreme events are attributable to global warming is debatable but they are evidence of environmental change. Climate models lead to the conclusion that future weather patterns will involve more flooding (Evans*, et al.*, 2008). Therefore there is the urgent need to ensure that our built environment can cope with such events and possibly more extreme future scenarios.

A major concern that engineers face with assessing buildings and structures is whether the foundations can deal with the current climate and if they will maintain their serviceability when faced with different climate patterns. UKCP09 climate projections (Murphy, 2009) predict that by 2080, based on medium emissions of greenhouse gasses, the UK could face increased rainfall during winter periods (50% probability level of 11-20% increase), higher temperatures and reduced rainfall during summer seasons (50% probability level of 2.5-3^{o}C increase in temperature and 4-9% reduction in rainfall) and more extreme storm events (heavy rain days to increase by a factor of between 2 and 3.5 in winter, and 1 to 2 in summer).

Flooding and drought events can produce changes in ground water level or change the ground water regime. A simple overview of the effects of changing water tables is given by (Chapman, 1999). Lowering of the water table can cause the soil to consolidate, which induces settlement. With softer, more compressible soils, settlements can become large. Inundation of water can potentially lead to collapse settlements of loose soils. In the UK this is generally only a problem for fill materials (Charles, 1996).

An equally important effect is the shrinkage and swelling of clay soils (Sanders, 2003). Foundation movements can lead to damage to buildings, the consequences of which can range from minor disruption that needs only redecoration to severe damage that requires structural intervention, e.g. underpinning. Sanders and Phillipson note that shrinkage and swelling of clay soils is the most common foundation-related cause of damage to low-rise buildings in the UK (amounting to insurance claims of £400 million per annum in 2003). These effects may well be exacerbated by warmer, drier summers and wetter winters.

2. Objective of the Review

An initial question was raised as part of the *Living with Environmental Change* initiative (www.lwec.org.uk) to address questions which relate to how environmental change could impact on the construction industry. A scoping study was undertaken to assess the feasibility of a Systematic Review to answer the following question:

Question: What is the impact of increasing changes in the water table on structural stability of buildings?

In this context "increasing changes" means environmental change could potentially bring greater occurrences of flooding and drought conditions, and more extreme examples of these events.

2.1. The Review Question

As a result of the scoping study it is proposed that the following changes be made to the research question for the full review:

Question: What is the impact of ~~increasing~~ changes in the water table and soil moisture on structural stability of buildings and foundation systems?

The proposed changes reflect concerns about possible ambiguity about the term "increasing changes" as this could be seen as referring to an increase in water level (i.e. a rise) rather than indicating more frequent or greater amplitude of changes. Including the "soil moisture" term recognises that significant effects due to environmental change can be induced by evaporation and infiltration without inducing changes in water table level. It was further felt that restricting the review to "structural stability of buildings" could potentially restrict the literature evaluated, when water-related effects could have similar impacts on other forms of construction (bridges, dams, roads, railways).

3. Methods

To conduct the review, an International review team has been assembled by the lead reviewer. The review team comprises leading international geotechnical engineers and hydrogeologists with specialist knowledge of environmental impacts.

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Stakeholder bodies with complementary expertise and with interests in the review are willing to provide a wider pool of knowledge who can also contribute to the review process. These are:

- British Geological Survey (BGS)
- Environment Agency (EA)
- National House Building Council (NHBC)
- Atkins
- Golder Associates
- Mott MacDonald

The first two bodies (BGS and EA) are Government funded institutions (BGS is funded through NERC). NHBC is an independent, non-profit distributing company that is the standard setting body and leading warranty and insurance provider for new and newly converted homes in the UK. Atkins, Golder Associates and Mott MacDonald are Civil Engineering companies whose work involves design and overseeing construction of civil engineering works in the UK and overseas.

3.1. Search strategy

Searches for the review will be carried out using the following bibliographic database systems:

EBSCO host
Geobase
InformaWorld
IngentaConnect
ISI Web of Knowledge
JSTOR
OCLC First Search
Science Direct
Springer Link

For "grey literature", the following web-based unstructured keyword search engines will be used:

http://www.google.com
http://www.scholar.google.com
http://www.scirus.com
http://www.alltheweb.com
http://www.dogpile.com

In addition, professional websites will be searched, as listed below:

British Geological Survey
British Hydrological Society
Building Research Establishment
Centre for Ecology and Hydrology
Construction Industry Research and Information Association
Construction Information Service
Dutch Geological Survey (TNO / Deltares)
Environment Agency
French "Argiles" network on swelling clays (http://www.argiles.fr/)
ICE Virtual Library
Inter-Governmental Panel on Climate Change
National House Building Council
Swedish Geotechnical Institute Information Service (SGI Line)
Tyndall Centre for Climate Change Research
UK Climate Impacts Programme

The following search terms are proposed by the review team.

Table 1. Search Terms

Set	Search terms
Set 1	***Subject terms*** Building Construction Foundation
	Effect terms Water table Ground water Flood Drought
	Outcome terms Instability Failure Collapse
Set 2	***Outcome terms*** Shrinkage Swelling Heave Subsidence Settlement
Set 3	***Outcome terms*** degradation wooden piles liquefaction

3.2. Study inclusion criteria

The following procedure will be adopted to identify the references that have greatest relevance and should be included in the study. After each search, records will be exported to a word processor document in tabular format displaying *Author, Year, Title, Source* (Journal or Conference title), *Volume, Number, Pages* and *Number of Citations*. Two further columns will be added for Rank and Comments.

The document containing the reference listing will be sent to all members of the review team. They will be asked to rank the relevance of each paper using:

0- Not relevant
1- Possibly relevant
2- Relevant

The team members will be free to add further comments if they wish. The rank scores awarded by each team member will be compiled and an overall percentage score of relevance will be calculated, where a 100% score indicates that all members of the review team have awarding an individual score of "2" (Relevant) to the record and a 0% score indicates that all members of the review team have awarding an individual score of "0" (Not relevant) to the record.

From the scoping study, it was found that for references with a ranking of less than 40%, usually no team member (at most 1 person out of 6) had identified a score of "2". This 40% level provides a natural cut-off point for inclusion of references. Therefore, references with a ranking below 40% will be excluded from further investigation.

For web-based unstructured searches (such as Google or Dogpile), a similar approach will be used. The first 50 records returned will be evaluated by the review team. A ranking of less than 40% will indicate the reference should be excluded from further investigation.

3.3. Potential effect modifiers and reasons for heterogeneity

The scoping study identified a wide literature that addresses the issue of the effects of changes in the level of the water table or changes in the ground water regime. It identifies problems in particular ground conditions such as peat, loess, clay soils, fills, chalk and karst (dissolution and sinkholes). It should be noted that there is also a large literature (40 references) on land subsidence in general, but many of these references do not refer to specific cases of building damage or foundation problems. However, the wide range of ground conditions and types of problems are likely to lead to considerable heterogeneity.

There is likely to be concern that most references addressing the topic of effect of water table changes are based on studies relating to reservoir filling or groundwater lowering as part of construction operations. There is very limited literature that specifically looks at effects of longer-term environmental change. Just one reference (Sanders, 2003) and the special issue of the journal Building Research & Information (Lowe, 2003) that includes the paper by Sanders, 2003 was found by the scoping study, and that reported expected effects rather than observations. While general conclusions on the effects of water table changes can be drawn from the available data, there is likely to be little evidence on the long-term and cyclical effects that will result from environmental change.

3.4. Study quality assessment

The scoping study suggested that most of the references on this topic are case studies, with each reference presenting an individual case. Much of the data may be qualitative descriptions of effects (reports of collapse or damage), although there may be quantitative measures of foundation movements or building performance in some cases. There appears to be no larger scale reviews relating to this topic. This certainly identifies a gap in existing knowledge and justifies the need for the review, but it means that the review will be time-consuming in compiling the individual cases. Judgements of quality will inevitably be based on the experience of the review team as there will be no simple determinant of quality.

3.5. Data extraction strategy

The majority of the references dealing with this topic will be case studies, with each reference presenting an individual case. Much of the information will be in qualitative form, so simple data extraction, as might be possible with quantitative data, is unlikely to be possible in this case. Each included reference will be read by a member of the review team who will write a summary paragraph extracting the key information. This will be reviewed by a second team member to ensure a consistent understanding of the original text.

3.6. Data synthesis and presentation

As part of the full review, a workshop will be held at Durham University, 25-26 March 2010 (http://www.dur.ac.uk/geo-engineering/iasworkshop/). This will allow the presentation of the review strategy and allow engagement with a wide range of experts and stakeholders.

4. Potential Conflicts of Interest and Sources of Support

Funding for the study was obtained from the Natural Environment Research Council under the *Living with Environmental Change* initiative. There are no conflicts of interest for the review team.

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