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Development of a long term monitoring network of sensitive clay slopes in Québec in the context of climate change — Source link

Catherine Cloutier, Pascal Locat, Denis Demers, Alexis Fortin ...+5 more authors

Institutions: Laval University

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Chapter 47
Development of a Long Term Monitoring Network of Sensitive Clay Slopes in Québec in the Context of Climate Change

Catherine Cloutier, Pascal Locat, Denis Demers, Alexis Fortin, Jacques Locat, Serge Leroueil, Ariane Locat, Jean-Michel Lemieux, and Chantal Bilodeau

Abstract The Government of Québec recently initiated the deployment of a vast groundwater pressures monitoring network in postglacial marine clays to document their variations in time and improve our understanding of the relationship between failure initiation and climate in clay slopes. This project aims at evaluating the impacts of climate change on clay-slope stability and how it can be integrated in landslide risk management to improve public safety. Hydrogeological data will be acquired at sites located throughout the Québec Province's post-glacial clay deposits to create a public georeferenced index of typical hydrogeological conditions. The project goes beyond the characterization of groundwater pressures and their variations in clay slopes. Indeed, slope deformation will be measured at several sites. Also, two sites in flat terrain will be instrumented in order to evaluate mechanical properties of clay layers in simple 1-D conditions and groundwater recharge. The unsaturated clay crust in slopes susceptible to superficial landslides will be characterized and instrumented. The current lifetime of the monitoring project has been set to a period of 25 years.

C. Cloutier (✉) • J. Locat • J.-M. Lemieux
Département de géologie et de génie géologique, Université Laval, Québec, QC, Canada
e-mail: catherine.cloutier.2@ulaval.ca; jacques.locat@ggl.ulaval.ca

P. Locat • D. Demers • A. Fortin
Ministère des Transports, de la Mobilité durable et de l'Électrification des transports du Québec, Québec, QC, Canada
e-mail: pascal.locat@transports.gouv.qc.ca; denis.demers@mtq.gouv.qc.ca; alexis.fortin@transports.gouv.qc.ca

S. Leroueil • A. Locat
Département de génie civil et de génie des eaux, Université Laval, Québec City, QC, Canada
e-mail: ariane.locat@gci.ulaval.ca

C. Bilodeau
Ministère de la Sécurité publique du Québec, Québec, QC, Canada
e-mail: chantal.bilodeau@msp.gouv.qc.ca

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47.1 Introduction

Naturally occurring landslides in sensitive clays are known to result from various causes including erosion (e.g. Lefebvre 1986; Locat et al. 2011), precipitation (e.g. Perret and Bégin 1997) and earthquakes (e.g. Lefebvre et al. 1991; Lamontagne et al. 2007; Locat 2011). For the first two causes, the link with climate can be made quite easily. Firstly, the climate influences the amount of precipitation (snow and water) and other parameters, such as evapotranspiration, which impact groundwater pressures in soil. Secondly, climate and meteorological events control river flow by governing the spring freshet, causing floods and drawdowns, which all influence erosion along river banks (Crozier 2010; Cloutier et al. 2016; Göransson et al. 2016). This concept is well accepted but still little is known about the actual geomechanical response of slopes to short and long term climatic conditions (Terranova 2002; Zêzere et al. 2004; Gauthier and Hutchinson 2012; Segoni et al. 2014; Marefat et al. 2015).

The general stratigraphy of clay deposits in Québec can be simplified to a clay of low permeability lying between more permeable layers consisting of an upper fissured clays or sand and lower till or fluvio-glacial deposits (Lefebvre 1986). Lafleur and Lefebvre (1980) explained how active river erosion deepens valley and influences slope stability by inducing changes to the groundwater regime in such a stratigraphy over hundreds of years. The effect of seasonal and inter-annual groundwater variations on effective stresses have also been studied, but data frequent enough to consider the effect of precipitation are limited. From various studies in clays (Jarrett and Eden 1970; Mitchell and Eden 1972; Berntson and Sällfors 1984; Kenney and Lau 1984; Sällfors and Svensson 1984; Lefebvre 1986; Boyle et al. 2009), we know that rapid variations of pore pressure are taking place in the upper more permeable layer and also, that significant seasonal variation can be observed in the lower permeable layer, but, because of its low permeability, pore pressure in the intact clay cannot follow these rapid variations occurring at its boundaries and the size of the variations decreases with increasing depth. Indeed, time lags are observed in between climatic conditions and the responses of piezometers in clays, which fluctuate with depth and spatial locations. The pore pressure response in clay is a function of its permeability and compressibility. In general, following spring snowmelt, groundwater pressure increases. Precipitation do not necessarily result in significant rises of the groundwater pressure as shown in the study of Boyle et al. (2009), probably due to the impact of vegetation, evapotranspiration and re-wetting of unsaturated soil. Finally, pressure gradient can change through the year (e.g. Berntson and Sällfors 1984).

Dragoni and Sukhija (2008) studied the possible impact of future climate change on water availability and discuss that in areas with increasing groundwater recharge, there will be increased slope instability. However, the ground becomes fully saturated relatively frequently in the environmental context of interest, and thus, ground saturation cannot be the main triggering mechanism for quick clay landslides (Boyle et al. 2009). So, in order to determine if landslide will become more frequent, the impact of climate change on pore pressure of clays and how they could lead to destabilization must be better understood.

Climate change projections tend towards a general increase in precipitation and in the frequency of extreme precipitation events in Québec (Ouranos 2014), which are known as triggering factors of landslides in clays. However, because climate change also impacts other variables more or less directly, such as evapotranspiration and the timing and magnitude of spring freshet, the impact of climate change on slope stability in post-glacial marine deposits is not straightforward. Key questions arising from mapping landslide susceptibility in this context are (1) how will slopes respond to climate change within the next 50–100 years and (2) how can it be taken into account to reduce landslide hazard. We believe that the first step in answering these questions is to develop a better understanding of the link between the initiation of landslides and the actual climate.

In order to move forward along this goal, the Government of Québec started a vast campaign of instrumentation of post-glacial clay deposits (Fig. 47.1) to characterize groundwater pressures and their variations in time. This project is part of the collaboration between the Ministère de la Sécurité publique du Québec (MSP), the Ministère des Transports, de la Mobilité durable et de l'Électrification des transports du Québec (MTMDET) and Université Laval that aims at contributing to the development of knowledge on slope stability in clay slopes. This collaboration is motivated by the wish to reduce the risk related to landslides in Québec, where 80% of them occur in clays (Fig. 47.1). Indeed, a large part of Québec's population lives on post-glacial marine clay deposits where landslides do occur every year (Demers et al. 2014). Most landslides have low consequences, but some have had high consequences (Potvin et al. 2001; Locat et al. 2014; Transport Québec 2011).

This long term project started in the winter of 2016 by the design of the instrumentation system and the choices of sites with the objective to set up a vast monitoring network. The network installation started in the summer of 2016 and shall continue in the next years. This paper presents the objectives and methodology developed so far to put in place the instrumentation network of groundwater conditions, slope deformations and weather to document climate change impacts on clay slope stability.

47.2 Objectives and Long Term Vision

This project will generate a database of groundwater conditions in post-glacial marine clays now located above sea level in the Province of Québec (Fig. 47.1). The four main objectives are: (1) to increase knowledge on seasonal and long term variations of groundwater pressures in clays, (2) to generate a georeferenced index of typical hydrogeological conditions in clays at different locations in the province to be consulted and used by engineers working with these soils, (3) to study the influence of climate change on slope stability in clays in Québec, and (4) to get a

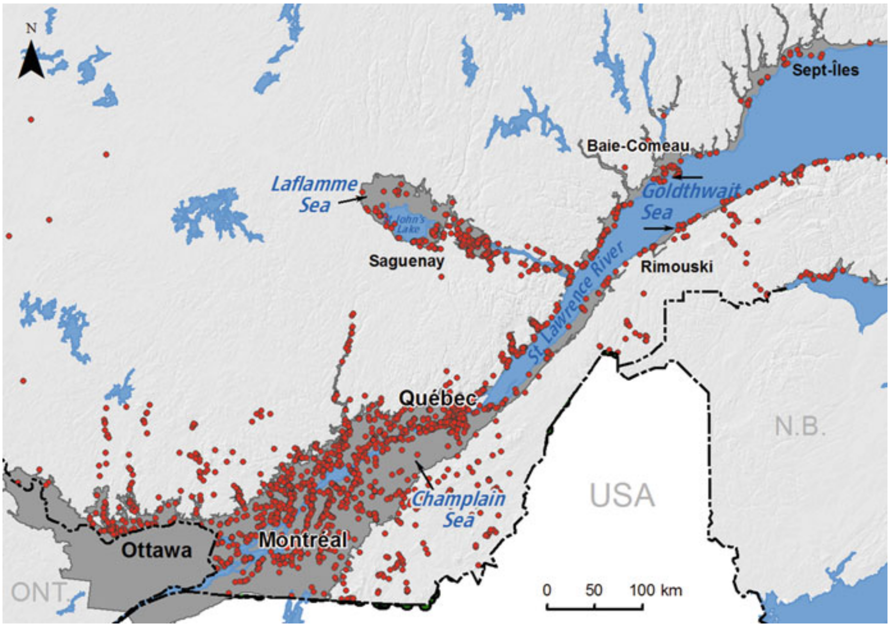

Fig. 47.1 Extent of post-glacial marine deposits (*dark grey zones*) and localization of the known landslides in all types of materials (*red dots*) in the Province of Québec

better understanding of the relationship between variations of groundwater pressures and soil deformations development in clay slopes.

This database should be useful to fill knowledge gaps in the mechanical behaviour of clay slopes. Some potential research themes that should benefit from the database are listed hereunder.

- Characterize mechanical properties, water pressures and deformations in clay soils by instrumenting site in flat ground and in slopes for a 25-year period;
- Improve slope stability analyses in clay slopes;
- Document and study the triggering role of groundwater pressures on deep-seated first-circular failure in clay slopes;
- Evaluate water and weather effects on the triggering of superficial landslides;
- Use climate models to project long term behaviour of clay slopes;
- Define warning criteria for weather and hydrological parameters linked to the landslide triggering;
- Examine the possibility to use real-time monitoring system as a risk management tool.

Keeping in mind theses research themes, five types of sites were conceived to be instrumented. Each type is intended to contribute to some of the listed specific themes, in addition to the four main objectives stated at the beginning of this section.

47.3 Methodology

To reach the scientific objectives, the final geographic distribution of the instrumentation network needs to respect some criteria. Indeed, it should cover the different climatic zones and the different projected climate changes. Moreover, the sites should represent the typical stratigraphy encountered in regions of the Province of Québec; hence, it should represent the various depositional contexts but still within sensitive clay slopes. Lastly, the sites should be placed in various morphologies, such as plains and valleys. The other criteria depend on the types of sites which are characterized by different morphologies and planned instrumentation (Fig. 47.2).

47.3.1 *Type 1*

Type 1 sites are those that are instrumented either for mapping landslide prone-area or for current slope stability studies carried out by the MTMDET. For mapping purposes, one piezometer nest of three sensors is usually installed at the bottom of valleys; while for stability studies a minimum of two nests of three piezometers are

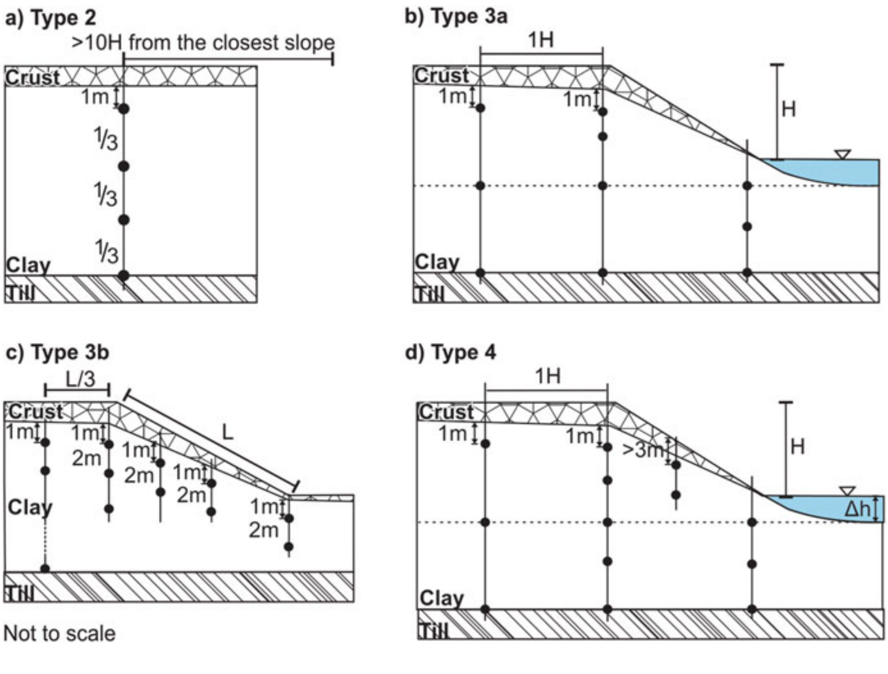

Fig. 47.2 Schematic representation of the 4 site types defined for the project showing the position of the piezometers (*black dots*). The type 1 sites are instrumented by the MTMDET for other purposes and have no typical morphology; this is why they are not drafted on this figure

installed at the top and at the toe of slopes. In both situations, the deepest piezometer often reaches the layer underneath the clay, which can be either till or fluvioglacial deposits. The data are acquired twice a day and saved on a data logger located at the ground surface and manually uploaded on site once a year.

A geotechnical characterization is also conducted, including grainsize distribution, water content, Atterberg limits, oedometer tests, and intact and remoulded undrained shear strength using vane, cone penetrometer test and Swedish fall cone. A digital elevation model (DEM) created from airborne laser scans and time series of aerial orthophotos are available.

Their localisation is chosen independently of the project criteria. Normally, these sites will be instrumented for a period of 3–5 years. However, they can match the criteria of the project, thus, certain type 1 sites could be transformed into types 3a, 3b or 4. Also, because they could offer an interesting spatial dispersion, their acquisition time span could be extended. In May 2016, about fifteen type 1 sites were already instrumented and there should be more in a near future.

47.3.2 Type 2

The instrumentation of the type 2 sites aims at characterizing mechanical properties of clays, hydrological conditions (infiltration, evapotranspiration, freezing depth) and groundwater pressure variations with depth in simple 1-D conditions. The instrumentation will be localized in a post-glacial clay deposit in flat terrain, located away from the closest slope by a distance at least ten times its height, to minimize the horizontal component of groundwater flow. Vegetation cover influence infiltration of water in slope and the vegetation cover will be characterized.

Type 2 sites have the most complex and complete instrumentation system of all five types. They will be located near sites type 3 or 4, as detailed information arising from these sites will help to analyse nearby, less densely instrumented sites.

The geotechnical characterization will include, in addition to what is listed for type 1, hydraulic conductivity, small strain deformation modulus (G_{max}, seismic cone penetrometer) and stratigraphic mapping. The instrumentation will include a minimum of three to four piezometers installed at different depths (Fig. 47.2a), a complete weather station, and sensors to characterize the vadose zone, evaluate water infiltration, and monitor ground temperature.

The acquisition frequency will vary with instruments, but should be around three times per hour for the sensors located in the unsaturated zone and four times per day for the piezometers. This will be adjusted in the final design.

47.3.3 Type 3a

These sites are meant to study groundwater conditions in slopes in sectors prone to deep rotational landslides, hence where recent landslides occurred or where scars were mapped. These sites should be selected with care to cover a range of morphologies, clay properties and regional hydrogeological contexts.

The geotechnical characterization will be similar to the one of type 1, but will include measures of hydraulic conductivity. Moreover, if there is a river, and this should be the case for most sites, its bathymetry should be mapped and water level could be monitored. The groundwater pressures will be monitored by a minimum of three nests of three piezometers (Fig. 47.2b). A weather station should be located nearby; the maximum distance from the site is still under discussion, but should be in the order of 5 km or less.

47.3.4 Type 3b

Sites of type 3b aim at studying superficial (∼3 m thick) landslides in the clay crust. The sites will be clay slopes without active erosion at their toe and where superficial landslides have occurred nearby. Climate change could have a potentially important effect on this type of instability. Indeed, the climate and the weather roles as aggravating and triggering factors of such failure types are well known (Perret and Bégin 1997; Terranova 2002; Crosta and Frattini 2003; Guthrie and Evans 2004).

The geotechnical characterization will be similar to the one of type 3a. In addition, the crust and its fissures should be characterized visually in trenches. The slopes will be monitored by four to five piezometer nests (Fig. 47.2c). The crust should be instrumented to monitor suction and water content. A complete weather station should be located within a close range, defined as less than 1 km.

47.3.5 Type 4

Sites of type 4 (Fig. 47.2d) will have the same geotechnical instrumentation and a similar piezometer installation as type 3a, but slope deformation (surficial displacements and displacement profile with depth) will be measured, potentially with InSAR technology and in-place inclinometers. To increase the chances to measure significant slope deformation, type 4 sites will be located on a riverside which undergoes active erosion and in a sector where recent landslides or past landslides are known. A nearby weather station and monitoring the river water-level are essential.

47.3.6 Piezometers

The network is to be maintained over a long period (25 years), thus, special care must be taken during piezometer installations to maximize the sensors' life span and data accuracy. Vibrating wire piezometers will be used and at least one Casagrande piezometer will be installed per site. Aside from type 1 sites, there should be only one piezometer sensor per borehole in order to limit vertical hydraulic short cuts. The sensor will be installed in a sand lantern with 60 cm-long plug of bentonite cement. The rest of the borehole will be filled with a mix of bentonite and Portland cements adjusted to insure that its permeability will be lower than the one of the soil. A barometer will be installed at sites of types 2 and 3b to correct the groundwater pressure for barometric pressure variations. Elsewhere, these variations will be estimated using data from the nearest weather station.

The piezometers should be installed deeper than frost penetration. For this reasons, the sensors should be at least 1 m below the clay crust (Fig. 47.2).

A hydrogeological model will be created for every site to place the piezometer data in their geotechnical context. This will be part of data validation. This project will generate an important amount of data, so a robust system should be develop to convert, validate and display the measured groundwater pressures.

47.4 Concluding Remarks

The first year of the project (2016) focussed on developing the design of the instrumentation, choosing the sites and starting the installation of piezometers on some sites of types 1 and 3a. Instrumentation of sites of type 2 and 4 were initiated in late 2016 and should be completed through the coming year. The documentation of groundwater pressures and their variations will lead to the creation of an index of hydrogeological conditions in clay deposits in the Province of Québec.

The short and long-term monitoring of clay slopes and the analysis of the data should allow a better evaluation of the occurrence probability of landslides and develop warning criteria adapted for climate change potential impacts.

To conclude, it is this the first time such an extensive monitoring project of sensitive clay slopes of Eastern Canada is being elaborated. The data originating from this monitoring network will benefit different research projects, but first, a little patience is mandatory to obtain data sets long enough to be meaningful.

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