Submission to Mccrae Landslide Board of Inquiry

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Introduction

Irrelevant and Sensitive

Irrelevant and Sensitive This submission is made by me as an individual expert. This his brief submission is made in response to a request dated 11 June ,2025 from the Chair of the Board. I have no connection at all with the Mccrae landslides or with any investigations or studies that might have been carried out in that area prior to or after the occurrence of landsliding. I asked for more information. John Aliferis, special advisor, replied on 13 June,2025 with a suggested list of documents(hyperlinked). I read significant parts of key documents; (1) Opening address Counsel Assisting. (2) Presentation of Expert Witness, Mr Darren Paul. (3) SMEC Expert geotechnical report. I did not read other submissions. However, it is important to note those submissions from stakeholders could contain important information.

I have published many papers in scholarly journals and in the Proceedings of International Conferences. I have also published several Books and Book Chapters.

Reference may be made to the following books of which I am the lead author:

Geotechnical Slope Analysis (2010), CRC Press/Balkema, Taylor &Francis Group,2010.

Geotechnical Slope Analysis, Second Edition (2024), CRC Press, Taylor & Francis Group,2024.

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Scope of this Submission

Available documents include photographs, description of the landslides and general ground conditions from visual observations. **This submission points out briefly what further work needs to be done to have a good understanding of landsliding that has occurred and similar instabilities that might occur in the future** . The planning of monitoring systems and designing of remedial measures against slope instability will depend greatly on a good understanding of the fundamentals

Subsurface investigations need to be more comprehensive. Minor geological or geotechnical details easily missed in routine subsurface investigations, can be critically important. For example, there may be a thin band of very weak soil very (loose sand, very soft clay) within an otherwise homogeneous soil layer. Causes of landsliding should include understanding of long-term processes including understanding of progressive failure mechanisms. Qualitative assessments of slope stability should be made using well known deterministic methods. While there are both simple and sophisticated methods of analysis available, the simpler method s will suffice in this instance. However, input data should be reliable. Quantitative probabilistic assessments are very useful for better understanding of risk.

There are references, in available documents, to the possible role of water such as seepage related to rainfall or water leaks from pressurised water mains. Definitive conclusions have not been reached.

Assessing Causes of Slope Failure/Landsliding

History of soil deposition and the period and intensity of urbanisation.

How stable was a slope before landslide occurred? And if that slope failed causing a landslide, how did instability occur? To be able to answer these questions, there must be a way to represent the stability of a slope. What about the potential for future slope instability in the whole area. In available documentation there is reference to 2022 and 2025 landslides and also to a landslide that occurred in the 1950s. It is necessary to have a geologist's considered perspective on the history of soil deposition in this area. It is also important to have good knowledge about the history of urbanisation in this area sloping area. It is well known that development of infrastructure in sloping areas can have delayed effects on slope stability in addition to short-term effects. The long-term effects may occur decares after urbanisation processes. The long-term effects would depend on the intensity of development, the type of soils and the role of water seepage.

Concept of factor of safety

This concept is often invoked to evaluate slope stability. It represents the ratio of shear strength to shear stress along a potential slip surface at a given point. This would represent a local factor of safety at that point. Thus, the local factor of safety may change from point to point along a potential slip surface. Over a slip surface of planar shape, it represents the ratio of the total resisting force to the total disturbing force. For rotational sliding, assuming a slip surface of circular shape, it is defined as the ratio of the resisting moments to the sum of disturbing moments. I found no mention of analyses in the documentation and not even references to factor of safety and its meaning.

What factors govern stability? It is well known that slope inclination, the geometry of the slip surface, the shear strength parameters of slope materials (cohesion (c) and angle of shear resistance (phi)) and pore water pressure (u) along the potential slip surface are the key factors that govern the stability.

The geotechnical engineer must draw typical cross-sections of the slopes being investigated showing the ground surface and the slip surface. I found no such cross sections in the documentation. Estimates of shear strength parameters must be made. I found no tables of shear strength parameters in the documentation.

Evaluation of factor of safety

The factor of safety is often denoted by F and evaluated in quantitative terms. A value of F greater than 1 indicates that a slope is stable. A value of F less than 1 indicates that the slope has failed or is expected to fail. A value of F=1 indicates critical equilibrium (a slope on the verge of failure). Estimates of factors of safety can be made based on the concept of limit equilibrium. There are a range of limit equilibrium methods. Before calculations can be made, data must be available on slope geometry, shape and location of the potential slip surface, soil shear strength parameters and the pore-water pressure. Pore-water pressure must be estimated based on observation or other assessment. I found no mention of actual or postulated values of pore water pressure u at the time of landslide or before the occurrence of landslide.

Shear strength consists of cohesive component and the frictional component. The latter is the product of effective normal stress and the tangent of the angle of shear resistance (phi).

The principle of effective stress

This principle governs the shear strength saturated soils. A soil layer in which the voids between solid particles are filled with water is called a saturated soil. The pressure in that water is called the pore-water pressure. Effective normal stress at a point is reduced by the magnitude of pore-water pressure. Consequently, the frictional component of the shear strength is decreased as well. The greater the pore water pressure, the less the frictional component of shear strength and hence the less the factor of safety. Inflow of water leads to seepage and as the top seepage line moves upwards within a slope (rise of water table), pore-water pressure increase**. Inflow of water which does not cause water table rise, and hence does not increase pore water pressure, has no adverse influence on the factor of safety.**

Partially saturated soils (also called unsaturated soils)

Such soils have both air and water in the voids and suctions (negative pore water pressures) can develop, the level depending on the type of soil. Such suctions increase the magnitude of factor of safety slope stability. If and when water inflow occurs such that the suctions , slope stability will decrease. The lowest value of factor of safety will correspond to complete elimination of suctions within the depth of potential landsliding.

Immediate triggers or Causes of Instability

What were the immediate causes of instability? For example, significant rainfall seepage can lead to high pore-water pressures. Thus rainfall-triggered landslides are very common. In cohesionless soils such as predominantly sandy soils, the factor of safety reduces drastically if seepage occurs throughout the depth of the slope.

If a slope has already failed, **back analyses** can be made to estimate values of one or more geotechnical parameters which are not known. I found no mention in the documentation of back analyses that may or may not have been performed for the landslides that have occurred.

I found no mention of significant rainfall events in days or weeks prior to landsliding. This implies that rainfall was not a trigger. However, variation of rainfall over months and years would be of considerable interest for long-term processes.

There are many references to investigation of water leaks from water pipes or sewerage mains and their possible contribution to the landsliding. The conclusions were that there was no possible connection of such leaks to the landslide sites.

Landsliding due to long-term processes

What are the long-term causes of instability?

It is difficult to outline all long-term processes that may have adverse impacts on slope stability. However, three important processes are listed below

a) **Modifications of slopes** over time in an urbanised area can include excavations, loading, construction embankments as well as disturbance of natural drainage patterns, surface and sub-surface.

b) **Decrease in shear strength parameters due to strain-softening**

It is important to note that shear strength parameters for a soil can change as stresses and strains change. With increasing stresses, strains and deformations, peak values of shear strength parameters may reduce to ultimate or residual values. This is an important aspect of what is termed as **progressive failure**.

c)**Pore-water pressure changes over time.**

The higher the pore water pressure in a saturated soil, the lower the shear strength and thus lower the factor of safety. Seepage patterns vary because rainfall often varies spatially and over time. The top seepage lines would rise and fall periodically.

d)**Elimination of suctions (negative pore-water pressures).**

In some slopes, at different times, there may be pore pressure suctions (negative pore water pressures). These negative pore pressures contribute to higher shear strength and hence higher factor of safety of such slopes in comparison to no pore-water pressure existing in the slopes. Over time, due to inflow of water (seepage from rain or other sources) would eliminate these suctions. Thus, shear strength would decrease and hence Factor safety would decrease, and the slope might fail.

e) **Progressive Failure**

There are many aspects of progressive failure and only some of these are mentioned in this section. The mechanism may be considered in terms of stress and strain concepts.

At some points within a slope the shear stress may be higher than the shear strength. These are overstressed locations with local factor of safety less than 1. With increasing strains and deformations, the shear strength parameters will be reduced depending on type of soil. The overstressed parts of a potential slip surface will this increase over time. A critical stage will be reached when the overall factor of safety F=1 and any slight decrease can cause catastrophic failure.

In some landslides the evidence of progressive failure may be evident during observations. Other landslides may occur very abruptly and suddenly. However, it is important to realise that the mechanisms of progressive failure may have contributed to the catastrophic failure. Extension of landslides by backward retrogression have been observed. Successive landslides can be observed in many cases in many locations around the world. Such phenomena are all governed by mechanisms related to progressive failure.

f) **Sub-surface soil erosion (internal erosion)**

It would be of great interest to investigate the possible of internal soil erosion in the Mccrae area. Is there any evidence of internal soil erosion at the landslide locations or at any other locations. If so, such processes could have contributed to weakening of the slopes and the occurrence of landsliding. The erodibility of soils could be investigated at selected locations outside landslide areas.

Slope monitoring, preventive and remedial measures.

The monitoring of slopes is important as part of a comprehensive observational approach. Results of analytical methods such as factor of safety values must be validated in the field. Moreover, the assumptions made for the geotechnical models must be checked and tested. What observational approaches were adopted at the sites of 2022 and 2025 landslides and for stable parts of the Mccrae area? Have the results been evaluated? Has any slope monitoring been carried out at typical sites within the stable parts of the slope? If so, the results should be evaluated to gain further insights on the overall stability

The objectives of prevention of further landsliding and minimising of losses requires that comprehensive field work be carried out in addition to analytical studies. These include:

Monitoring of surface movements at selected locations

Monitoring sub-surface deformations at selected locations

Monitoring pore-water pressures at selected locations.

Based on such monitoring and the insights gained from qualitative and quantitative assessments, preventive and remedial measures should be designed and carried out.

Probability of failure and risk assessment.

The assessment of slope stability may be complemented by approaches within a probabilistic framework. There are variabilities and other uncertainties in the basic slope parameters, such as shear strength and pore water pressure. Deterministic methods do not include consideration of uncertainties.

A probabilistic approach allows consideration of such uncertainties, and the results are expressed in terms of values of probability of failure. The factor of safety F is treated as a random variable (rather than as a single-values constant). A random variable follows a probability distribution which may be represented by the mean and the coefficient of variation, cov.

The probability of failure pf decreases as mean factor of safety increases (keeping cov constant) but pf is never zero. Acceptable values of probability of failure for slopes and other geotechnical structures have been suggested from time to time based on experience in the field.

Assessment of slope risk, especially in built-up urban areas would require consideration of the probability of failure, pf, as well as the consequences of failure and hence the value of the assets which are at risk from slope failure or landsliding

It is suggested that indicative studies be carried out for Mccrae area to assess the range of probabilities of slope failure within the whole.

It is also suggested that the stakeholders be asked to carefully consider the level of probability of failure and risk that they can accept or tolerate. A probability of failure of 0.05(5 percent) may be acceptable for natural slopes in a non-urban setting provided there are no consequences to life or safety or damage to property.

However, in an urban area, stakeholders may wish to have lower values of probability of failure a magnitude lower, say 0.005(0.5) percent. If remedial and strengthening measures are required to achieve this, then the costs have also to be considered.

For major structures such as earth dams, catastrophic failure of which could impact many lives and cause huge financial damage, acceptable probabilities of failure would have to be several orders of magnitude lower ,say 0.00001 (0.001 percent).