Lessons from application of geoenvironmental policies regulating development

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ABSTRACT
Toronto and Region Conservation Authority (TRCA) regulates development in areas prone to geoenvironmental hazards using a set of specific policy provisions. These provisions were formulated taking into account conditions occurring along the watershed valleys and stream corridors. Such conditions include: the size and geometry of valley slopes, evidence of erosion and the recession in time of the top of slope, as well as the setback of slope crest from proposed development. In reviewing the permit applications for development, TRCA staff is looking at the determination of the long-term stable top of slope based on guidelines provided by the Ontario Ministry of Natural Resources. The paper presents lessons extracted from this direct experience acquired in the permitting process.

RÉSUMÉ
L'Agence Territoriale de Toronto pour la Conservation de l'Environnement applique des provisions régulatrices concernant la construction dans les zones naturellement hasardeuse. Ces provisions ont été formulées en considérant les conditions rencontrés sur les vallées des rivières et dans les ravines. Les conditions regardent les formes de relief, la géométrie des pantes, l'évidence d'érosion causée par les courants d'eau et la distance relative entre la crête du pante et la construction proposée. En revoyant la documentation pour le permis de construire, le personnel de l'agence vérifie le calcul pour la ligne stabile de la crête du pante basé sur la guidance fourni par le Ministère des Ressources Naturelles. La communication présente les leçons appris pendant le procès de revue des permis.

1 TRCA'S REGULATORY ROLE

Under the Conservation Authorities Act, a permit is required for waterway alteration, grade change or construction in natural hazard areas. TRCA is one of the local environmental agencies managing such permits, through Ontario Regulation 166/06. The TRCA jurisdiction covers over 2400 square kilometers, including the City of Toronto as well as part of the Regional Municipalities of Peel, York and Durham (Figure 1).

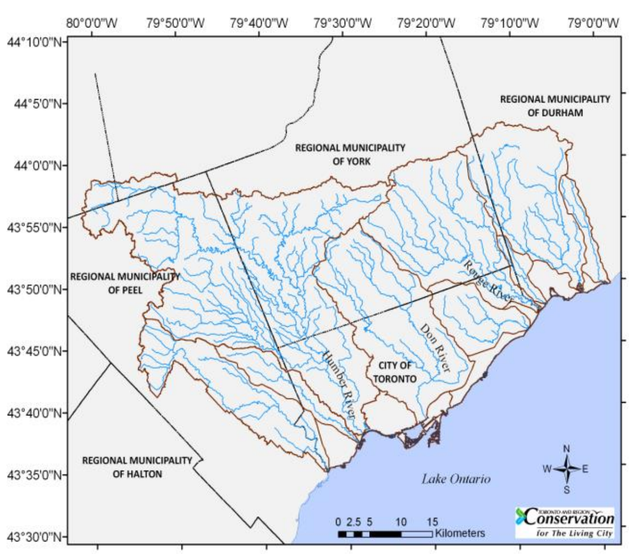

Figure 1. Toronto & Region Conservation Authority jurisdiction (TRCA IT/GIS Group)

With the intensification and expansion of urbanization along valley lands and stream corridors, the risk of exposure to natural hazards has increased tremendously in the past few decades. In this light, the TRCA Planning staff's main mandate is the delineation of the developable limits in the proximity of stream corridor slopes and ravines. Using technical knowledge, the TRCA staff has developed policies and criteria to support the regulatory provisions.

1.1 Geoenvironmental Policies and Criteria

Provisions regarding the geoenvironmental aspects and criteria are presented in several chapters of the TRCA policy document (TRCA, 1994). They reflect conditions such as occurrence, geometry and size of landforms in the proximity of proposed development. Some of those conditions trigger the need for a geotechnical stability assessment. Two of the criteria considered in this context are the height and the steepness of the valley or ravine slope.

Of particular essence in determining the developable limits is the long-term stable top of slope (LTSTOS) line. The LTSTOS is the imaginary projection, over a 100-year span, of the existing top of slope (ETOS). Once the LTSTOS line is determined, developable limits are delineated by applying the 10-metre buffer policy provision (TRCA, 1994).

A guideline issued by the Ontario Ministry of Natural Resources (OMNR, 2002) is utilized to determine the LTSTOS. Two types of allowance described in the OMNR Guideline are of interest to the TRCA review team: toe erosion allowance and stable slope allowance. These two elements are schematically illustrated on Figure 2.

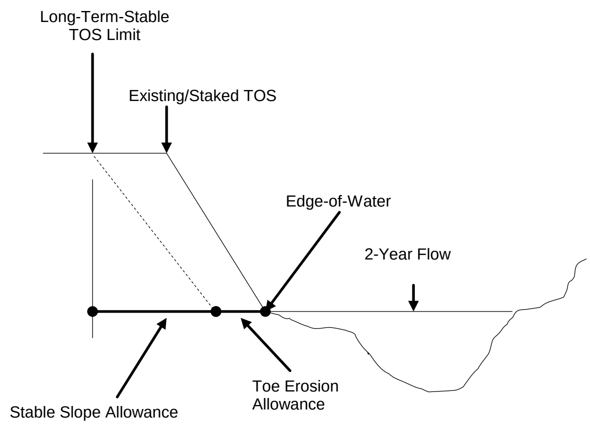

Figure 2. Schematic explanation of the toe erosion allowance and stable slope allowance

A subsurface investigation usually provides enough information for the two allowances to be determined. However, along stream corridor reaches with significant channel bank erosion, a geomorphic study may be warranted to assess the toe erosion allowance.

TRCA staff has developed a set of requirements for development permit applications (TRCA, 2007). One of these requirements is a geotechnical assessment of the LTSTOS in the light of the aforementioned OMNR Guideline.

1.2 Geotechnical Study

The terms of reference and complexity of a particular geotechnical study vary from site to site. Among the factors that determine the complexity include significance of the landform, severity of the observed or potential hazard, and the proximity of proposed development to the valley.

TRCA staff reviews the geotechnical studies prepared by engineering consultants and submitted on behalf of the proponent. In reviewing each study, staff verifies not only the way in which the geotechnical engineering principles were applied but also whether the Factor of Safety criterion was met. The minimum figure required by the TRCA for the Factor of Safety is 1.5 (TRCA, 1994 and 2007).

2 LESSONS FROM CASE STUDIES

Most of the permit files submitted to the TRCA are for new construction proposals, redevelopment, or structural additions. Municipal projects, such as road widening, transportation improvements, bridges, culverts, sewer pipelines or parkland development are also subject to permitting if they encroach into a regulated area. A particular level of complexity is associated with properties where severe runoff erosion has led to loss of tableland.

In the following sections, generic case studies based on commonly encountered issues are discussed, with a view to the lessons learned. Their exact site locations are not provided because of confidentiality concerns and also because they are meant to represent common conditions.

2.1 Runoff Erosion Undermining Ancillary Structure

Although the 10 metre setback of dwellings from the LTSTOS line is in general observed, ancillary structures, such as swimming pools, patios or decks are sometimes permitted closer to slopes. The construction of numerous such structures had preceded the issuance of the TRCA policy document, a time when the regulatory strictness was weaker. Situations of that kind are in a relatively great number within the City of Toronto boundaries.

Figure 3 illustrates the conditions and mechanism of failure for a deck pole caisson whose embedment is subjected to progressive erosion. The main cause of the erosive process is stormwater runoff; however, a major factor is the location of the pole's caisson over the slope. Runoff on a slope is much more erosive than on a relatively flat surface because of the higher velocities. Thus, although the caisson is founded in a competent native stratum, side erosion of the embedment leads to its gradual loss of stability. The mechanism and result of erosion is independent of the methodology used to install the caisson.

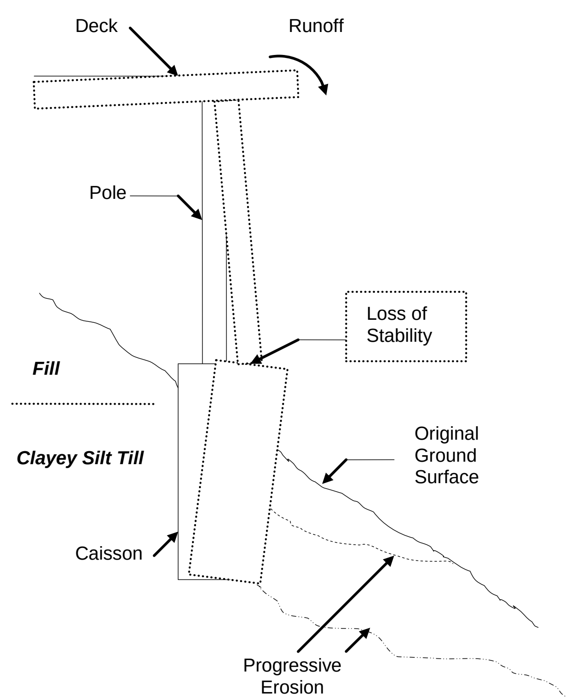

Figure 3. Schematic conditions and mechanism of erosion undermining a founding caisson

A replacement of the collapsed deck within the same footprint not only would be contrary to the current policy provisions but would also lead to the same mechanism of failure, resulting in risk of injury and loss of property. Visual monitoring of the slope and prompt intervention could have prevented the loss of stability.

2.2 Channel Erosion Undermining Bank Protection

At sites involving bank protection, a geomorphic study or a meander-belt analysis is required to determine the tendency and amplitude of potential channel migration. The design of protective measures to stop further bank erosion and slope instability needs to also consider potential downcutting of the channel bed. A geotechnical investigation to determine the soil composition and strength parameters may also help in the assessment of a conservative rate of downcutting. Long-term monitoring of watercourse reaches along which bank protection was installed can be used to validate the average annual rates of downcutting and channel migration.

Figure 4 is a schematic illustration of bank protection failure and slope instability encountered at a number of urban locations across the TRCA jurisdiction. These failures can be the result of inadequate studies in the preliminary phases or the underestimation of erosion rates at the design stage. In some cases, the proponents underestimated the magnitude of the design storm and/or the channel capacity to convey it without significant impacts.

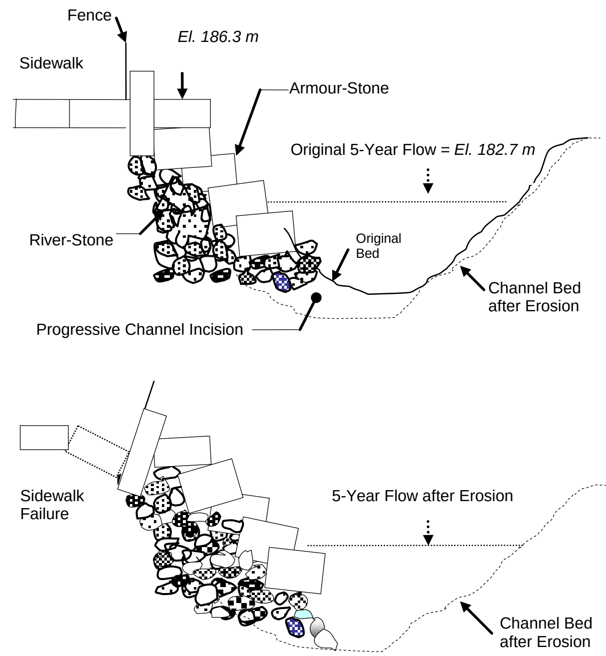

Figure 4. Schematic mechanism of channel undercutting and geoenvironmental impact

In the TRCA jurisdiction, positive experiences were recorded with use of deeply embedded structures in front of the wall, such as crib-walls or vegetative rip-rap. Those environmentally-friendly protection methods are relatively quickly integrated into the fluvial system and provide a greater flexibility to channel bed erosion. Figure 5 shows an example of crib-wall with willow growth used on the Etobicoke Creek in the City of Mississauga.

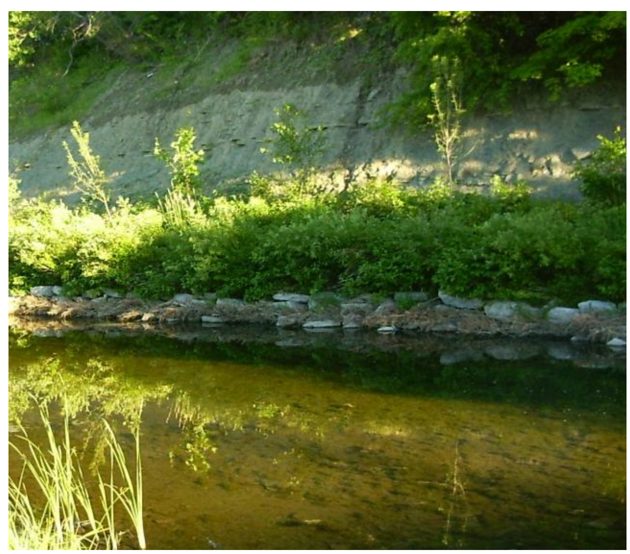

Figure 5. Toe of slope protection with crib-walls on the Etobicoke Creek West Branch in the City of Mississauga (photo: Tudor Botzan)

2.3 Erosion and Instability of Fill

Rear yards fronting deep ravines are widespread, especially within the City of Toronto. Over 80% of those locations were developed several decades ago, before the current TRCA regulatory policies were in place. Since numerous lots along those ravines have small rear yards, landowners have been tempted to use fill materials in order to expand their amenity space. With the exposure of fill soils to years of rainfall, runoff and seepage, steeper slope tops progressively erode and tableland is lost to the ravines. The losses are greater in winters with abundant snowfall, and are sometimes associated with slump failure of the fill material.

Figure 6 exemplifies the general occurrence of fill erosion or instability. Apart from slope inclination, the two major factors involved with fill instability were the degree of compaction and composition of soil materials.

The degree of compaction is generally well reflected in the blow counts (N-value) recorded during drilling. However, after years of use of rear yards and access of re-grading equipment, the existing N-values may misrepresent the original level of fill engineering. The best behaviour of fill materials was encountered where a balanced proportion was used between impervious fractions (clay, silty clay, clayey silt) and free-draining soils (sand, silty sand, sandy silt).

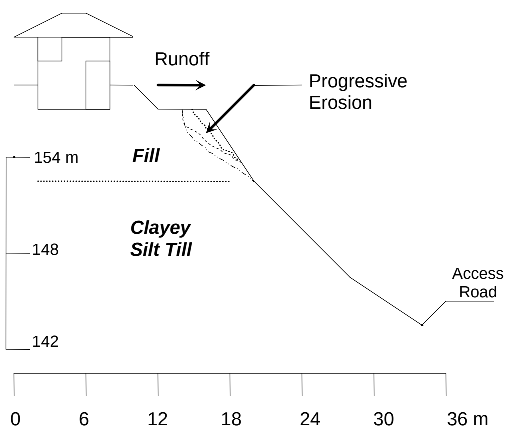

Figure 6. Schematic conditions of fill erosion in the residential rear yard due to runoff and other factors

2.4 Road Side Stormwater Collection

Many municipal development projects reviewed by the TRCA staff involve road widening. Inevitably, some of the roads proposed for widening cross watercourses or run parallel to valleys. Land ownership is the main issue associated with acquisition of lands to widen roads, and the high cost of acquisition in the Toronto area makes these projects a challenge.

In widening a road, engineered fill is used to extend the road sidewise, adjacent to the valley slope. The new slope's upper portion is, in most of the cases, inclined at a gradient of about 2 Horizontal to 1 Vertical (2H : 1V). For an engineered fill slope to be stable at 2H : 1V, an appreciable level of compaction is required. Moreover, the fill material's water content needs to be in the neighbourhood of its optimum, as determined through the standard Proctor test. Such requirements are difficult to fulfill under the pressure of deadlines and in uncontrollable weather conditions.

Beside the geotechnical considerations described before, stormwater collection ditches are rarely sized for significant storm events because of the issues associated with land acquisition. The runoff generated during heavier storm events overtops the ditch side, flowing over the face of the adjacent slope (Figure 7). Repeated or long term runoff flow over the fill-made slope, the temporary super-saturation of the fill material, as well as long contact of that soil with snow and ice, are just some of the most frequent causes of road embankment failure or erosion.

2.5 Development on Fill Materials

Many properties along valley slopes or ravines are too small to accommodate residential development. In the past, infilling was used to expand the tableland area (Figure 8) in order for these residential lots to accommodate larger homes.

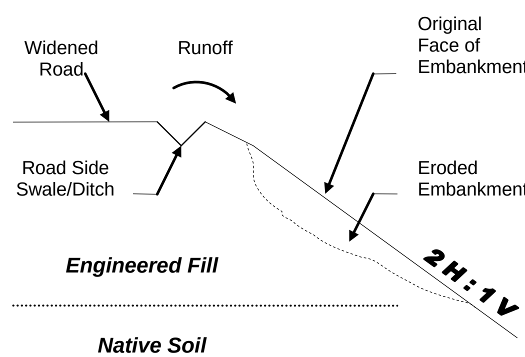

Figure 7. Schematic conditions of road-side erosion

In the situations where some of the structural footings were founded on fill materials, inadequately engineered, differential or excessive settlements occurred. As a result, cracks appeared in different sections of the walls, often visible from outside the house.

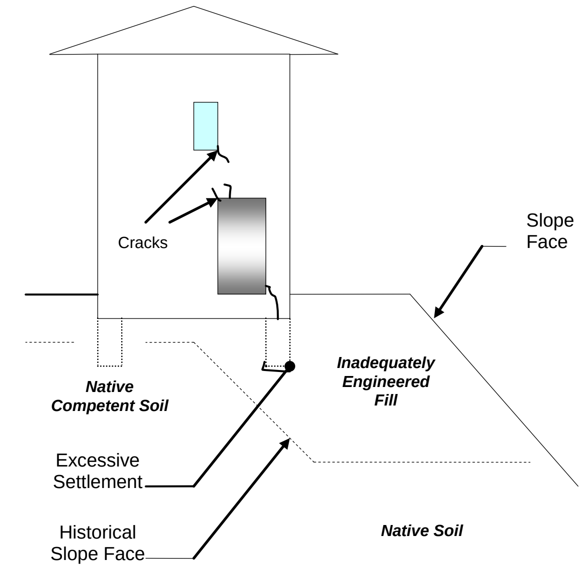

Figure 8. Schematic illustration of structural cracking due to improper founding conditions

In reviewing permits for redevelopment on residential lots with a history of infilling, the TRCA staff requires a subsurface investigation to delineate the extent of fill. Such delineation allows for the new dwelling's foundations to be lowered down to the competent native stratum, whether through open excavation, shoring or drilled caissons. Where outstanding evidence of slope erosion is noted, an assessment of the LTSTOS is also required in order to re-evaluate the developable limits.

2.6 Underestimation of Toe Erosion Allowance

The aforementioned OMNR Guideline provides tabulated toe erosion allowance ranges based on the soil type encountered at the respective location. The main criterion used in this estimation is the horizontal distance between the 'edge of water' and existing slope toe, or floodplain width. For distances greater than 15 metres, the Guideline provision is a zero toe erosion allowance. In other words, it is considered that a slope whose toe is over 15 metres away from the 'edge of water' would not be eroded in a time horizon of 100 years. It is therefore assumed that the average erosion rate or migration of the channel bed towards the respective bank is less than or equal to 0.15 m per year.

A legitimate question is the definition of the 'edge of water': it is roughly the watermark left by the 2-year flow on the channel bank, also called the bank-full level (Figure 9). This definition is endorsed by most agencies and consultants.

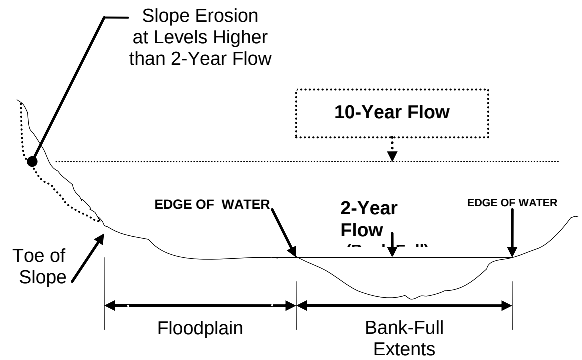

Figure 9. Schematic definition of the 'edge of water'

In some permit applications reviewed by the TRCA staff, the implemented toe erosion allowance has proven to be underestimated. Several significant storm events have occurred in the past decade, culminating with the August 19, 2005 storm. Post-storm inspection of several creek bank sectors clearly indicated evidence of erosion at elevations higher than the bank-full water level (Figure 9).

Figure 10 schematically illustrates one of the multiple cases where the recommended toe erosion allowance should have been increased. The change in the cross-sectional configuration of the subject slope, after the occurrence of the referenced storm event, is indicated on the figure. The original and the conservative LTSTOS limits are delineated by the intersection of the two parallel "Stable Slope Inclination Lines" with the ground surface, respectively.

The banks and slopes the most affected by the August 19, 2005 storm were situated along the Humber River, Don River and Highland Creek. However, numerous ravines across the City of Toronto, usually dry, were filled with water during the storm and were subjected to severe erosion.

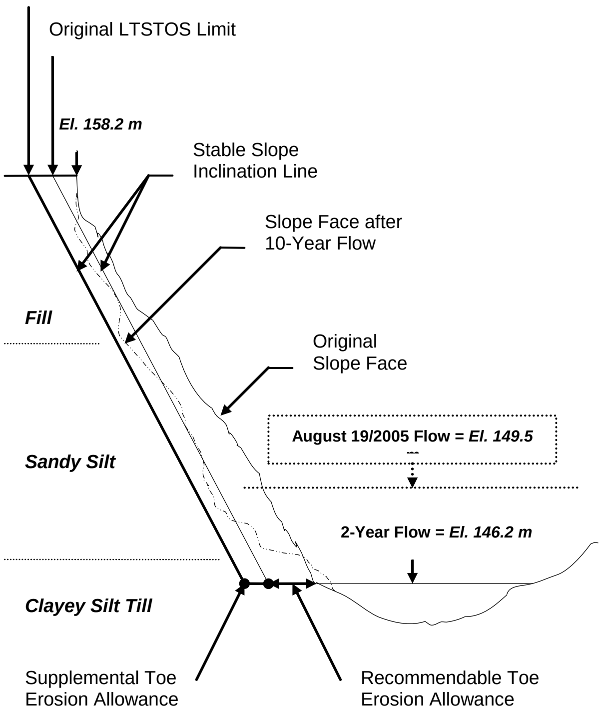

Figure 10. A schematic illustration of the supplemental toe erosion allowance

2.7 Landslides

Several landslides of medium to major proportions were recorded within the TRCA jurisdiction in the last decade. Those slope instability events resulted in a relatively significant loss of tableland adjoining the existing development.

The landslides occurred both on the Scarborough Bluffs and major river valleys such as Humber and Don. Their main triggering factors were over-saturation due to significant seepage, combined with abundant runoff. In some instances, the aforementioned seepage was likely the result of sudden thaw during major spring rainfall.

Other events leading to an irreversible loss of tableland consisted of creeping chunks of ground at the top of slope, along various valleys and ravines. In those cases, the incidence of substantial runoff over slope tops consisting of loose fill was the dominant mechanism of the progressing creeping. Slope steepness was a definite contributing factor.

Figure 11 illustrates a simplified view of the conditions at one of the landslide locations on the Scarborough Bluffs. The Scarborough Bluffs are geomorphological formations along the northern shoreline of Lake Ontario. A portion of about 14 km along this shoreline comprises bluffs with heights of about 30 to 80 metres with variable slope inclinations. In the section shown on the figure, the slope inclination in the upper one-third of the height would be between 0.6H : 1V and 0.8H : 1V. In the middle third, it would be about 1.2H : 1V to 1.5H : 1V, becoming 1.8H : 1V or flatter in the lowest third.

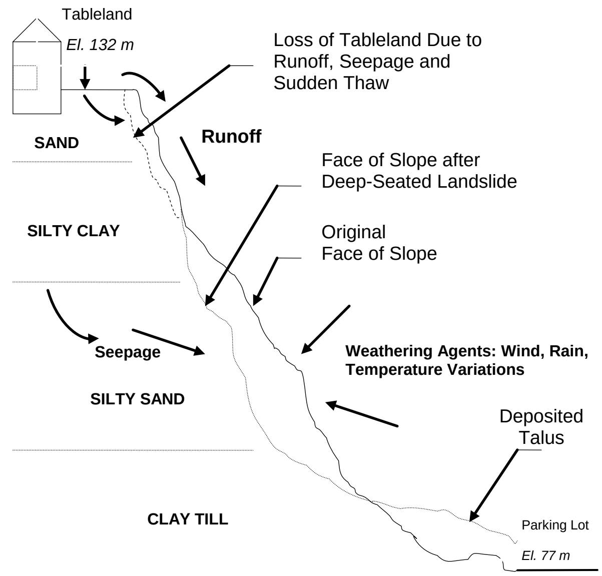

Figure 11. A schematic illustration of the landslide conditions

Due to their near vertical slope, the upper portion of the bluffs is generally devoid of vegetation and is continually eroding under the action of weathering. This unique geoenvironmental setting requires conservative approaches in the estimation of the LTSTOS.

3 CONCLUDING REMARKS

One of the TRCA's main regulatory roles is delineation of developable limits in the proximity of conservation lands, stream corridor slopes and ravines. The decision support system for permitting of development on lands with risk to natural hazards consists of policies meant to protect the large public and their private properties.

The main geoenvironmental instrument utilized in the screening and review of development applications is the LTSTOS line, which represents a hazard limit. In support of the LTSTOS assessment, the OMNR has developed a Guideline. Two of the components described in the OMNR Guideline are of interest in what the assessment of hazard limit is concerned: toe erosion allowance and stable slope allowance. A geotechnical investigation and a slope stability analysis against a Factor of Safety of minimum 1.5 are required to enable a review of the hazard limit.

Some of the most typical situations of slope instability, toe undercutting and runoff erosion, encountered by the TRCA review staff, were presented in the paper. Each category of case described has a relatively high level of generality. Nevertheless, the geoenvironmental hazard having acted is, in every case, triggered by site-specific and time-specific conditions and stressors.

4 ACKNOWLEDGEMENT

The author is thankful to Mr. Don Ford, Manager of the TRCA's Geoenvironmental Group, for his valuable suggestions as well as for reviewing the paper.

TRCA IT/GIS staff has assisted with the map production as well as with the editing of figures, for which I would like to thank Mr. Chris Gerstenkorn, Mr. Dan Clayton and Mr. Andy Bowler.

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