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Vision for Geotechnical Asset Management at Alberta Transportation

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ABSTRACT
Geotechnical assets such as soil and rock slopes, retaining walls, embankments, and subgrades play a crucial role in the functioning of transportation networks. These same assets also pose potential threats to the transportation system as a result of deteriorating condition, escalating maintenance costs or catastrophic failures. Alberta Transportation is responsible for managing approximately 500 identified geohazard sites through the province. This paper will describe Alberta Transportation's current Geohazard Risk Management Program (GRMP), and the vision for transforming this program into a formalized Geotechnical Asset Management (GAM) program. The goals of GAM at Alberta Transportation are to enhance the Department's ability to monitor the condition and deterioration of the geotechnical asset inventory, forecast future funding requirements to achieve desired levels of service and risk reduction, and facilitate evidence-based decision making that considers the full life cycle costs and benefits of our geotechnical assets.

RÉSUMÉ
Les actifs géotechniques tels que le sol et les pentes rocheuses, les murs de soutènement, les remblais et les sous-couches jouent un rôle crucial dans le fonctionnement des réseaux de transport. Ces mêmes actifs constituent également des menaces potentielles pour le système de transport en raison de la détérioration de l'état, de l'escalade des coûts de maintenance ou de défaillances catastrophiques. Alberta Transportation est responsable de la gestion d'environ 500 sites géorisques identifiés dans la province. Ce document décrira le programme de gestion des risques géographiques (GRMP) d'Alberta Transportation et la vision de la transformation de ce programme en un programme officiel de gestion des actifs géotechniques (GAM). Les objectifs de GAM chez Alberta Transportation sont d'améliorer la capacité du Ministère de surveiller l'état et la détérioration de l'inventaire des actifs géotechniques, de prévoir les besoins de financement futurs pour atteindre les niveaux de service et la réduction des risques souhaités, et de faciliter la prise de décisions fondées sur des preuves qui tiennent compte de la pleine coûts et avantages du cycle de vie de nos actifs géotechniques.

1 INTRODUCTION

Alberta's provincial highway network comprises more than 31,000 two-lane equivalent kilometres of roadway infrastructure. These interconnected transportation corridors facilitate the safe and efficient movement of people and goods throughout the province. The provincial highway network is a vital public resource, which supports and enhances Alberta's economic vitality, community connectivity, and overall prosperity.

Transportation corridors are made up of many interdependent components including bridges, pavements, and geotechnical features, such as soil and rock slopes, earth embankments, retaining walls, and subgrade soils. Alberta Transportation (AT) manages approximately 500 identified geohazard sites along the provincial highway network. This paper describes Alberta Transportation's current Geohazard Risk Management Program (GRMP), and the vision for transforming this program into a formalized Geotechnical Asset Management (GAM) program.

2 GEOHAZARD RISK MANAGEMENT PROGRAM

2.1 Program Objectives

Alberta Transportation's strategic mandate is to support the province's *"economic, social and environmental vitality by developing and preserving a safe, efficient and affordable multi-modal transportation system"* (Alberta Ministry of Transportation, 2020).

In support of the strategic mandate, Alberta Transportation's Geohazard Risk Management Program (GRMP) was established in 1999. AT's Technical Standards Branch is responsible for overseeing the monitoring and management of geohazard sites throughout the province. The program objectives support the ongoing safety and reliability of the provinicial highway network by:

- Proactively identifying unstable geotechnical sites (geohazards), and inspecting these on an annual or semi annual basis;

- Assessing the relative level of risk posed by each geohazard site using prescribed guidelines, to assist in prioritizing mitigation strategies that achieve risk reduction through geotechnical capital maintenance and renewal projects;
- Identifying, investigating and monitoring short-term (maintenance) and long-term (rehabilitation or replacement) strategies for geohazard sites, to improve the highway safety and reliability by reducing the risk of geotechnical failure.

The short-term outcomes of the GRMP enable Alberta Transportation to respond to and repair geohazards that are directly affecting the highway system, such as a rock fall that has forced the closure of a lane of traffic, or a landslide that will imminently damage a neighbouring bridge abutment.

The long-term program objectives are aimed at proactively identifying emerging geotechnical issues, and prioritizing interventions before full-scale failures occur. The sites in the GRMP inventory are monitored, inspected, assessed and repaired within a risk-based prioritization framework.

(a) Soil Slope (b) Rock Slope (c) Embankment (d) Retaining Wall (e) Subgrade

Figure 1: Examples of Sites in Alberta Transportation’s GRMP Inventory

2.2 Current Geohazard Inventory

Alberta Transportation owns and maintains the geohazards which are located within the provincial highway right-of-way. The 2019 GRMP inventory consisted of approximately 500 documented sites. 213 of these sites are active geohazard locations, which pose ongoing risks to the safe and efficient operation of Alberta’s highways; the remaining sites represent geotechnical features which are currently inactive or have been repaired (posing a negligible risk to highway operations). The GMRP inventory includes unstable soil and rock slopes, embankments, retaining walls and subgrades, as illustrated in Figure 1. In Alberta, common subgrade issues include frost heave, swelling, settlement, erosion, and sinkholes (due primarily to dispersive soils and abandoned underground coal mine workings). Unstable soil slopes and embankments make up 78% of the active inventory (166 sites), with unstable subgrades, retaining walls and rock slopes comprising the remaining 22% (47 sites, Figure 2). Approximately 60% of geotechnical assets in the active inventory (by repair value) are located on Level 1 and 2 highways, and the remaining 40% are located on Level 3 and 4 highways[1].

The GRMP inventory is not fixed in its size. New sites are added to the inventory every year, as unstable geotechnical features are identified by highway maintenance contractors and regional staff. The GRMP inventory was populated with approximately 100 known sites in 1999, and has grown to approximately 500 sites in 2019. The size of the inventory can be substantially impacted by natural forces such as severe weather events that lead to flooding and landslides, for example. The length of time for which a geotechnical asset resides in the active GRMP inventory, from the time it is identified until it is repaired, will depend upon the initial inventoried condition, the rate of deterioration, the potential consequences related to its failure, and the availability of funding for replacement or repair. On average, approximately five to ten sites are repaired/replaced per year, depending on available funding.

In addition to identified geohazards, there are many constructed assets, such as retaining walls and embankments, which could be added to the geotechnical inventory in the future. Those currently included in the inventory are primarily retaining walls which have been built to stabilize a landslide, or embankments which have been identified as unstable. Separate databases also exist for debris flow and corridor rock fall hazard assessments. Expanding the current inventory to include more comprehensive information on all geotechnical hazards and constructed assets is one of the future goals as the GRMP matures into a Geotechnical Asset Management program.

[1] Alberta’s Provincial Highway Service Classification is hierarchical, and ranks existing highways based on their function to the traveling public, as follows (Stantec 2007):
Level 1 (National Highway System routes): International and inter-provincial traffic.
Level 2 (Arterials): Intra-provincial traffic.
Level 3 (Collectors): Inter-county traffic.
Level 4 (Locals): Intra-jurisdictional or traffic within a localized area.

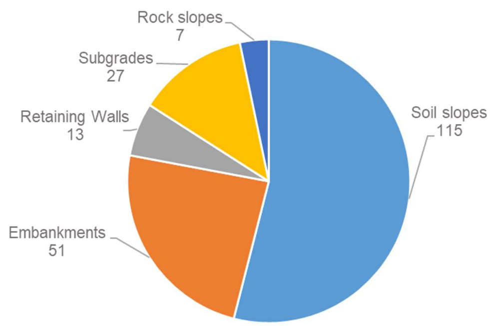

Figure 2: Active Sites in 2019 GRMP Inventory

2.3 Field Inspections and Risk Level Rating System

Alberta Transportation's Geohazard Risk Management Program (GRMP) includes annual or semi-annual field inspections and twice-annual instrumentation readings at all of the active sites in the inventory (213 active sites in 2019). The recurring GRMP inspections facilitate risk-based prioritization of the sites for remedial action. The inspections also allow AT to document the history and institutional knowledge of the sites, facilitating a more effective and expedient response to geohazard threats as they materialize.

For the purposes of the program administration, the sites are divided into seven geographical areas that correspond to AT Region and District boundaries (Edson/Stony Plain, Athabasca, Grande Prairie, Swan Hills, Peace River/High Level, Central, and Southern).

Geotechnical consultants perform the field-level inspections and instrumentation readings through a Geotechnical Services Contract administered by AT Regional Offices. The consultant service contracts are four-year terms, with optional one-year extensions. The duration of the consultant contracts promotes in-depth understanding of the sites and expedites repairs. Detailed design and tender packages are prepared by the consultant responsible for the GRMP area.

Alberta Transportation's Technical Standards Branch engineers and Regional staff accompany the consultants on the annual field tours, and review the findings of the field inspections and instrumentation reports. In addition to the scheduled inspections, emergency call-outs are completed by the consultant responsible for the geohazard area on an as-needed basis. Approximately five emergency call-outs per year are included in the consultant services contract for each district.

Based on the field inspection observations and instrumentation readings, each geohazard site is assigned a risk level on a scale of 1 to 200. Alberta Transportation defines the risk level as the product of the probability factor (or likelihood of failure on a scale of 1 to 20), multiplied by the consequence to the safety and efficiency of the roadway (on a scale of 1 to 10). The risk level rating scale for unstable soil slopes and embankments is shown in Table 1. AT uses similar risk rating scales for rock slopes (developed by AMEC 2006) and erosion sites. At the end of 2019, the average risk level rating for the 213 active sites in the GRMP inventory was 41. As indicated in Figure 3, there are currently 22 geotechnical sites in the active inventory with risk levels ≥ 75, including ten sites with risk levels ≥ 100. These 22 sites have a total estimated repair cost of approximately $60 million (equivalent to approximately four years of backlog based on 2019 capital program funding).

The GRMP inventory and risk level data are managed in AT's internal Geohazard and Materials Management Application (GAMMA) which is part of AT's umbrella Transportation Information Management System (TIMS).

The GRMP informs operational and capital improvements for managing geotechnical risks which impact or threaten to impact the safety and reliability of the provincial highway network. Alberta Transportation develops an annual geotechnical capital maintenance and renewal (CMR) program based on the relative risk level ratings of the active sites in the GRMP inventory, and additional considerations including: the Highway Service Classification (Level 1, 2, 3, 4), the rate of change in the risk level rating, the importance of the corridor to the local community, and consultation with Regional staff. The Department-wide CMR program also facilitates coordination of geotechnical repairs with other highway capital projects.

2.4 Limitations and Future Work

Simplicity is a core element of the current risk level rating system used in the GRMP. This simplicity is also one of the limitations of the program. For example, the current GRMP risk level rating system does not include any measure of risk exposure. Therefore, an impending landslide on a busy Level 1 highway, with 4,000 vehicles exposed per day, would have the same risk level as an analogous feature on a Level 4 highway with only 400 vehicles passing per day. Future modifications to Alberta Transportation's GRMP risk level rating system could incorporate average annual daily traffic (AADT) or Highway Service Classification as a proxy for exposure. The Oregon DOT's well-known Rockfall Hazard Rating System (RHRS), for example, incorporates exposure through the *Average Vehicle Risk* factor, which is calculated based on the AADT (Pierson 1992).

The movement rate descriptions used in the GRMP risk level rating system could also be improved for clarity and repeatability of probability factor selections. The current velocity descriptors (perceptible, very slow, moderate, high) could be replaced with established terminology, such as from Cruden and Varnes' (1996) landslide velocity scale. Due in part, perhaps, to the ambiguity of the current velocity descriptors, the upper end of the probability factor scale (Table 1) is rarely used.

While the GRMP risk level rating system provides a relative ranking of sites for remediation, the risk levels are qualitative in nature, and do not allow for direct comparison with other capital projects competing for funding, such as a pavement rehabilitation or a bridge replacement project. Integration of the GRMP outputs into a cross-asset capital rehabilitation program requires considerable judgement and subjective intervention. In its current form the GRMP provides necessary inputs to some aspects of an asset management program (such as asset inventory, condition and relative risk), but does not facilitate cross-asset comparisons, nor strategic decision making based on benefit-cost ratios, monetization of risk, life-cycle deterioration modeling, and forecasting of future needs.

Table 1: GRMP Probability and Consequence Factors for Earth Slides

Probability Factor, PF (rated on a scale of 1 – 20)	
1	Inactive, very low probability of slide occurrence.
3	Inactive, low probability of remobilization.
5	Inactive, moderate probability of remobilization, uncertainty level moderate, or active but very slow rate of movement or indeterminate movement pattern.
7	Inactive, high probability of remobilization or additional hazards, uncertainty level high, or active with perceptible movement rate and defined zone(s) of movement.
9	Active with moderate steady, or decreasing, rate of ongoing movement.
11	Active with moderate by increasing rate of movement.
13	Active with high rate of movement, steady or increasing.
15	Active with high rate of movement with additional hazards.
20	Catastrophic slide is occurring.

Consequence Factor, CF (rated on a scale of 1 – 10)	
1	Shallow cut slope where slide may spill into ditches or fills where slide does not impact pavement, minor consequence of failure, no immediate impact to driver safety, maintenance issue.
2	Moderate fills and cuts, not including bridge approach fill or headslopes, loss of portion of the roadway or slide onto road possible, small volume. Shallow fills where private land, water bodies or structures may be impacted. Slides affecting use of roadways and safety of motorists, but not requiring closure of the roadway.
4	Fills and cuts associated with bridges, intersectional treatments, culverts and other structures, high fills, deep cuts, historic rock fall hazard areas. Sites were partial closure of the road or significant detours would be a direct and unavoidable result of a slide occurrence.
6	Sites where closure of the road would be a direct and unavoidable result of a slide occurrence.
10	Sites where the safety of public and significant loss of infrastructure facilities or privately owned structures will occur if a slide occurs. Sites where rapid mobilization of large scale slide is possible.

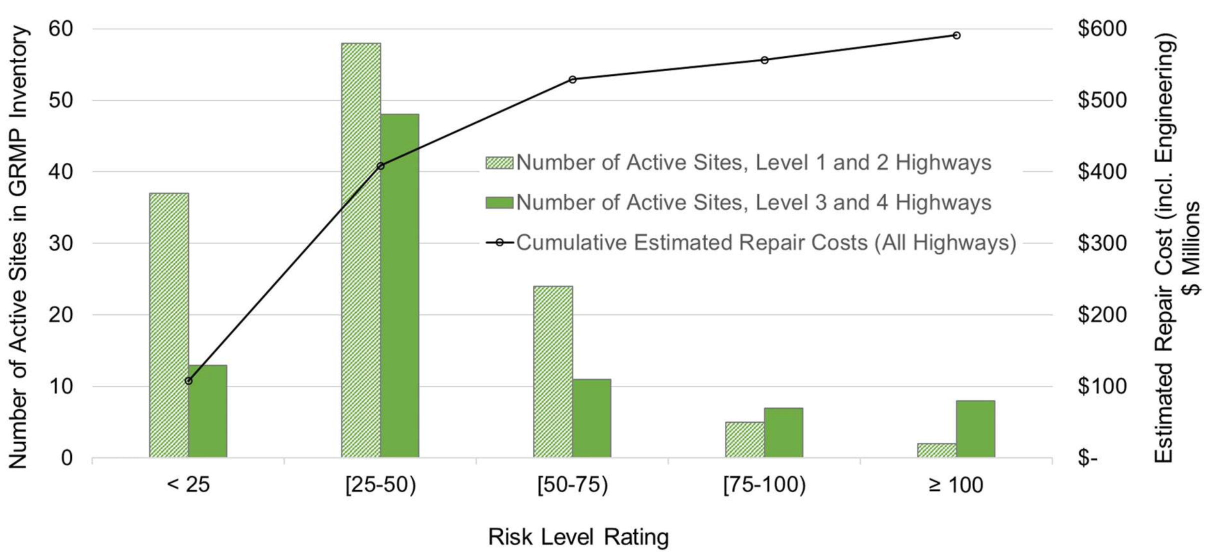

Figure 3: Risk Level Rating Distribution and Estimated Repair Costs for Active Sites in the GRMP Inventory (2019)

3 GEOTECHNICAL ASSET MANAGEMENT

3.1 Overview and Taxonomy

Asset management is defined as a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their life cycle; it focuses on economic analysis and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well-defined strategic goals (NCHRP 2009). In simple terms, asset management is the process of making decisions about the use and care of infrastructure, to deliver services in a way that considers current and future needs, manages risks and opportunities, and makes the best use of resources (Alberta Municipal Affairs, 2015). Implementing asset management principles commonly allows agencies to shift from reacting to failures as they occur, to proactively and systematically prioritizing work, maintaining assets in acceptable condition, and identifying cost-effective treatments to prolong life (NCHRP 2019).

Processes for managing risks to linear infrastructure posed by geohazards are relatively well established within the engineering community, and have been used by AT since 1999 (also see for example, Vessely et al. 2019). Geotechnical asset management takes these processes a step further by: including constructed geotechnical assets in addition to natural hazards in the inventory, developing deterioration models specific to geotechnical assets, applying these models with unit cost estimates to forecast future risk levels and funding needs, and estimating the optimal timing and cost-benefit ratio of interventions (see for example Anderson et al. 2017, NCHRP 2012, and Thompson 2017).

The ISO 55000 Standard (2014) defines an asset as an *"item, thing or entity that has potential or actual value to an organization. Value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities; it can be positive or negative at different stages of the asset life."* Geotechnical assets can be defined as physical, independent assets that are present within the highway right-of-way, which contribute to the safe and efficient operation of the transportation corridor (Anderson et al. 2016). The taxonomy from Anderson et al. (2016) organizes geotechnical assets into four broad categories:

- slopes,
- embankments,
- retaining walls,
- subgrades.

As depicted in Figure 4, the four categories of geotechnical assets can be further described by their primary material composition, e.g. soil, rock, debris or modified (for slopes). Anderson et al.'s (2016) taxonomy of geotechnical assets includes both natural and constructed geotechnical features within the highway right-of-way as "assets". Natural hazards and deteriorating earth assets can be viewed as separate threats with similar consequences for a transportation agency: travel disruption and delays, user injury or fatality, damage to vehicles or adjacent property, and escalating costs of deferred maintenance (Vessely et al. 2019). For the purposes of this discussion, both geohazards and constructed earth assets will be referred to as "geotechnical assets", in the terminology of Anderson et al. (2016), and in accordance with the ISO 55000 definition (2014). From Alberta Transportation's perspective, geohazards are considered geotechnical assets in the sense that future capital expenditures are required to maintain or repair these sites. Moreover, from an agency risk management perspective, geohazards and constructed earth assets generate similar risks to linear infrastructure, and their (often interdependent) performance needs to be managed to achieve agency objectives (Vessely et al. 2019).

3.2 Examples from Other Jurisdictions

Public agencies are beginning to recognize the potential benefits of taking a proactive, systematic approach to the management of geotechnical assets (including geohazards), and geo-professionals are developing tools for the inventory, condition assessment, life-cycle cost prediction and risk assessment of geotechnical assets.

Since 2012, Transportation Asset Management has been mandated in the United States through the U.S. Federal authorization, MAP-21, and its current successor the FAST Act. In order to qualify for Federal funding, all U.S. State Departments of Transportation are required to submit risk-based Asset Management Plans for bridges and pavements on the National Highway System. They are also encouraged (though not required) to prepare Asset Management Plans for ancillary assets located within the highway right-of-way, including geotechnical assets. To support the inclusion of geotechnical assets in an agency's transportation asset management plan, NCHRP (2019) Report 903 provides a research overview, implementation manual and Excel spreadsheet tools for agencies seeking to establish geotechnical asset management programs.

One of the key objectives outlined in Alberta Transportation's 2020-23 Business Plan is to *"implement an asset management approach to support strategic decision-making on new assets and ensure adequate maintenance of existing assets, taking into account life-cycle costs, and economic, safety, environmental and social impacts"* (Alberta Ministry of Transportation, 2020). In response, Alberta Transportation's Technical Standards Branch has recently drafted the Department's first Transportation Asset Management Plan, which includes pavements, bridges, and geotechnical assets.

The Colorado Department of Transportation (CDOT) has also recently implemented a Transportation Asset Management Plan that incorporates geotechnical assets and geohazards (Anderson et al. 2017). CDOT classifies retaining walls as geotechnical assets, and inspects the visible elements of the walls based on the National Bridge Inventory (NBI) ratings, assessing the wall condition and potential consequences to highway mobility and maintenance. Slopes, embankments and subgrades are managed together as geohazards, considering threat likelihood as an annual probability of failure, and monetized consequences to highway mobility, maintenance and safety. The total risk is expressed in dollars to facilitate project prioritization, and to demonstrate a favorable benefit-cost ratio for certain proactive interventions (Anderson et al. 2017).

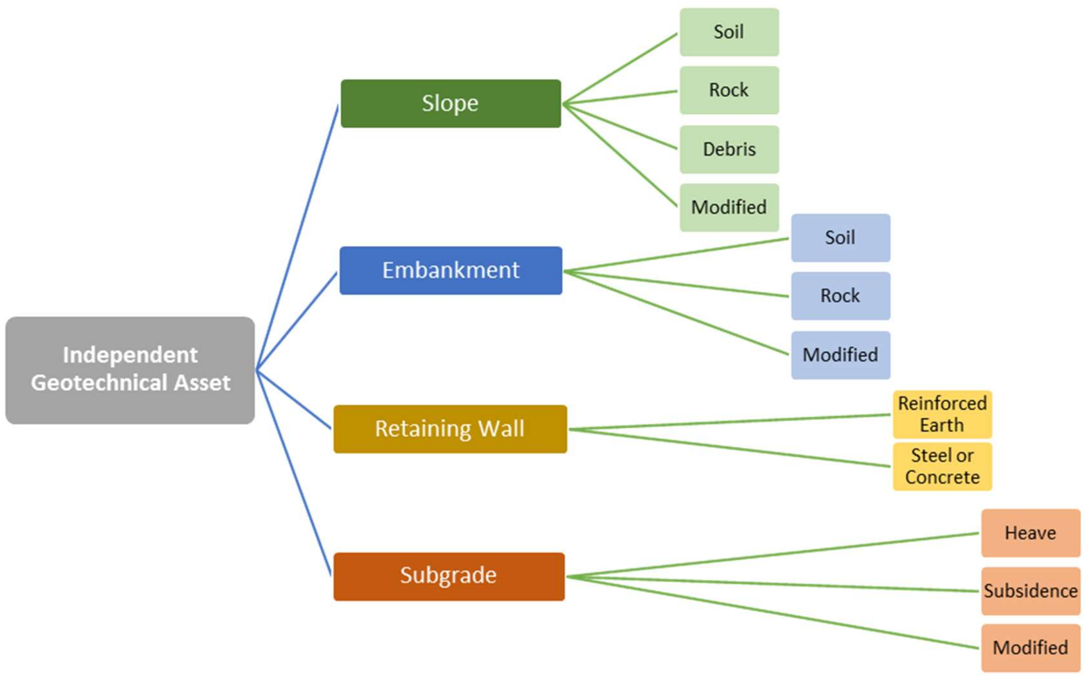

Figure 4: Taxonomy of Geotechnical Assets (modified from Anderson et al. 2016)

The Ohio DOT has an asset management system which includes approximately 18,000 inventoried geohazards (landslides, rock fall sites and abandoned underground mines) in a publically-accessible geographic information system (GIS) online platform (ODOT 2020). A risk-based matrix is used to assess the likelihood of movement and potential consequences to the highway, in order to categorize the geohazard risk as Tier 1, 2, 3, or 4. The risk tiers are used to determine the frequency of re-inspection, and the priority for repair. Repaired sites are not retired from the inventory, but are included as assets with expected future maintenance and rehabilitation/replacement needs (Merklin 2020).

In 2017, the Alaska DOT published a comprehensive Geotechnical Asset Management Plan for slopes, embankments, retaining walls and material (borrow) sites, with simple deterioration models to aid in management and needs forecasting for geotechnical assets (Thompson 2017).

Numerous other jurisdictions and infrastructure owners in the United States and Canada have risk-based management systems in place for selected geotechnical assets, such as retaining wall management systems or rock fall hazard management systems.

Outside of North America, asset management practices across a wide portfolio of assets, including geotechnical assets, are well-established elsewhere. In the United Kingdom for example, embankments and slopes have been included in risk-based asset management programs for Network Rail and the U.K. Highways Agency since the 1990's (Power et al. 2016 and Arup 2010). Together, these two agencies manage nearly 250,000 slopes and embankments using asset management principals (Vessely et al. 2019).

3.3 Performance Measures and Objectives

Transportation asset management uses asset-specific performance measures to evaluate the effectiveness of a transportation system. Performance measures are set based on financial, technical, policy, and economic considerations. Due to the variety and complexity of geotechnical assets (natural and constructed slopes, embankments, retaining walls and subgrade soils), performance measures for these assets are typically risk-based (AASHTO 2020). In order to measure and report on progress towards agency objectives, each performance measure is usually assigned a performance target (PIARC 2017). Performance targets should be achievable and affordable in the agency-specific operational and financial context, and should relate the asset performance to the agency's strategic objectives (e.g. highway safety, efficiency, and preservation).

Alberta Transportation's GMRP risk level rating system can be considered a risk-based performance measure, as it relates the potential impacts of geotechnical assets to the safety and efficiency of the highway network. The risk levels can be grouped into performance categories of Very Good/ Good/ Fair/ Poor/ Very Poor, as shown in Table 2. As part of the draft Transportation Asset Management Plan, AT is working to categorize pavements and bridges using a similar set of descriptors, to enable a high-level comparison of the state of the Department's highway assets.

Beyond the performance measures, very few agencies, including AT, have established performance targets for geotechnical assets. Based on experience with the GRMP program to date, Table 2 presents suggested minimum performance targets for geotechnical assets. The minimum suggested performance target on Level 1 and 2 highways is a risk level of 75 (fair) or lower, while for geotechnical assets on Level 3 and 4 highways, a risk level of 100 (poor) or lower is recommended. The lower level of risk recommended for Level 1 and 2 highways acknowledges the higher number of vehicles exposed, and the more substantial the consequences of failure, compared to Level 3 and 4 highways. The recommended performance targets for geotechnical assets are based on balancing a tolerable level of risk to the safety and efficiency of the highway system in a fiscally-constrained environment. The fourth column in Table 2 shows the spectrum of recommended actions, from an agency perspective, that are initiated based on the risk level rating (or geotechnical asset performance). For lower-risk sites, these include ongoing monitoring via recurring inspections and instrumentation readings. Once a geotechnical asset's risk level exceeds approximately 50, AT typically initiates engineering studies to identify suitable repair and/or replacement strategies, recognizing the multi-year timelines for subsurface investigation, options analysis, detailed design and construction.

Alternatively, if the traffic volume and detour length do not justify the cost of repairs, permanent closure can be contemplated for a secondary (Level 3 or 4) highway. AT is working towards establishing policies for rationalizing the highway network (i.e. candidate road or bridge closures that could be considered based on a benefit-cost approach).

Table 2: Proposed Management Framework for Geotechnical Assets Based on Risk Level Rating

Risk Level (RL) Rating	Performance Description	Highway Service Classification: Level 1 and 2	Highway Service Classification: Level 3 and 4	Spectrum of Recommended Actions
< 25	Very Good	Acceptable Performance	Acceptable Performance	Infrequent Inspections
[25-50)	Good	Acceptable Performance	Acceptable Performance	Regular Inspections
[50-75)	Fair	Acceptable Performance	Acceptable Performance	Instrumentation/ Repair Options Analysis
[75-100)	Poor	Actively Prioritize for Mitigation	Acceptable Performance	Detailed Design and Tender
[100-200]	Very Poor	Actively Prioritize for Mitigation	Actively Prioritize for Mitigation	Rehabilitation, Replacement, Closure[1]

[1] Permanent closure may be contemplated for Level 3 and 4 highways only.

3.4 Deterioration Models

Beyond the current asset condition or risk level rating, an important component of asset management is the application of deterioration models. These models allow for forecasting the performance of the asset inventory into future years, facilitating capital budget planning and cost-benefit analyses of intervention options.

Unlike the more well-established deterioration models used for pavement and bridge management, a unique challenge for many geotechnical assets is that their deterioration curves may approximate step functions, where severe but infrequent natural events exert a dominant impact on their performance (Anderson and Rivers 2013). Notwithstanding, while adverse geotechnical events may be perceived as uncommon and unpredictable at the local scale, total needs and impacts can be reasonably predicted on an aggregated regional basis, using deterioration models that are specific to geotechnical assets.

The simplest deterioration model using condition state data is a Markov model, which expresses deterioration rates as probabilities of transitions between the possible condition states each year (Thompson 2017). Markov deterioration models are frequently used in bridge management systems, and also in some pavement management systems as well. NCHRP (2012) documents the development of Markov deterioration models specifically for geotechnical assets. Table 3 below summarizes the deterioration models developed by the Alaska Department of Transportation for soil slopes, rock slopes, and retaining walls, based primarily on expert elicitation (Thompson, 2017). The models are predicated on an asset condition or risk rating scale which ranges from State 1 (no action needed) to State 5 (major mitigation required).

The transition time shown in Table 3 is the estimated number of years that it takes for 50% of a representative population of assets to deteriorate from each condition state to the next-worse one; the same-state probability is the statistical probability, in any one year, that a given asset will remain in the same condition state one year later. If the transition time is known or estimated, that same-state probability, p_{jj}, is computed using Equation 1 (Thompson 2017):

$$p_{jj} = 0.5^{\left(\frac{1}{t}\right)} \quad [1]$$

Where j = condition state (before and after 1 year)
t = transition time in years

The condition of the inventory in any year can be expressed as the fraction in each condition state. The fraction in any given condition state after one year is computed by multiplying the current fraction in each state by the corresponding same-state and next-state probabilities. This calculation can be repeated as many times as desired in order to extend the inventory condition forecast into the future (Thompson 2017). The simplified Markov models presented in Table 3 limit the transition of an asset in any given year from one state to the next worse one.

It is proposed that as part of AT's GAM program development, geotechnical asset-specific deterioration models will be adapted and refined for the Province's growing inventory of slopes, embankments, retaining walls and subgrades. Initially, these deterioration models would be informed by a literature review, and AT's experience with the GRMP. As asset-specific condition data is collected over time as part of the GAM program, these models can be refined in an evidence-informed manner.

Table 3: Markov Deterioration Models for Geotechnical Assets (after Thompson 2017)

Soil Slopes	Starting Condition State				
	State 1	State 2	State 3	State 4	State 5
Transition time (years)	55.0	23.1	12.6	7.6	—
Same-state probability	0.9875	0.9704	0.9465	0.9128	1.0000
Next-state probability	0.0125	0.0296	0.0535	0.0872	0.0000

Rock Slopes	Starting Condition State				
	State 1	State 2	State 3	State 4	State 5
Transition time (years)	38.3	32.5	21.2	13.7	—
Same-state probability	0.9821	0.9789	0.9678	0.9507	1.0000
Next-state probability	0.0179	0.0211	0.0322	0.0493	0.0000

Retaining Walls	Starting Condition State				
	State 1	State 2	State 3	State 4	State 5
Transition time (years)	25.2	20.8	8.3	7.2	—
Same-state probability	0.9729	0.9672	0.9199	0.9082	1.0000
Next-state probability	0.0271	0.0328	0.0801	0.0918	0.0000

3.5 Life Cycle Cost Analysis

Once asset-specific deterioration models have been established, a life cycle cost (LCC) analysis can be performed to establish the optimal type and timing of interventions, as described in NCHRP (2019). In brief, the basic inputs to the LCC model are the:

- Set of states (condition states) defined for the asset.
- Set of treatments that can be performed in each state, including a 'do minimum' treatment. NCHRP (2019) utilizes five treatment options: 1. Do minimum; 2. Maintenance; 3. Rehabilitation; 4. Reconstruction; 5. Restoration (assumes full failure has taken place).
- Unit costs for each treatment option (including discount rate).
- Treatment effects. Treatment effects are described using probabilities of transition from the current state to every other state, given the performance of a specific treatment. The deterioration of the asset can be described through the effects of the 'do minimum' treatment.

Once the LCC model inputs have been defined, a linear optimization equation can be formulated and solved to determine what actions, if taken, will minimize asset life cycle costs over time (NCRP 2019). The benefit of performing a treatment is the difference in overall cost resulting from performing a treatment compared to deferring the work for another year ('do minimum' option). If the difference is non-zero, it will be more cost effective to perform the treatment than to defer the work. Dividing this calculated benefit by the treatment cost gives a benefit-cost-ratio (BCR) for prioritizing mitigation projects (NCHRP 2019).

4 INVESTMENT STRATEGIES AND NEXT STEPS

Legacy management practices have often viewed geohazards (and by extension, geotechnical assets), as inherently unpredictable, deferring maintenance or treatment options until failure forces unplanned action (NCHRP 2019). This creates a growing backlog of geohazard sites that cannot be repaired in a proactive manner, resulting in a sub-optimal resource allocation strategy.

A reactionary, "run to failure" approach results in direct mitigation costs that are higher for emergency repair situations than for programmed work, and potentially higher overall life-cycle costs due to a lack of preventative maintenance. Moreover, the indirect economic and social costs of a geotechnical failure can be substantial— for example, an unmitigated landslide can force the full closure of a vital highway corridor, completely disrupting traffic flow and corridor connectivity while emergency design and reconstruction takes place. There is also an implicit acceptance of an unknown level of risk to the safety of the traveling public, when assets are allowed to fail before initiating restorative action.

Asset management incorporates asset worth, asset condition, and risk factors into decision making, to optimize the use of funds in building, operating, and preserving the transportation system (NCHRP 2019). In addition to network preservation and expansion, asset management principles can inform decision making around rationalizing the highway network (i.e. permanent closures or divestment of assets). Aligning with the Ministry of Transportation objectives, AT's strategic vision is for the transformation of the Geohazard Risk Management Program into a formalized Geotechnical Asset Management program, facilitating better decision-making based upon readily available information and well-defined objectives.

AT has recently engaged an engineering consultant to assist in the development of the Geotechnical Asset Management (GAM) program framework. The GAM program will enhance the Province's ability to monitor the condition and deterioration of our geotechnical asset inventory, forecast funding requirements to achieve desired levels of service and risk reduction, and facilitate evidence-based decision making that considers the full life cycle costs and benefits to the highway network of our geotechnical assets. A key component of future GAM implementation will be the procurement of a supporting geospatial software tool for paperless data collection, visualization, management and decision-making.

5 CONCLUSION

Alberta Transportation's strategic business plan (AT 2020) and current best practices encourage the adoption of formalized Asset Management strategies for guiding the operation, maintenance, upgrading and expansion of transportation assets throughout their entire life cycle.

Alberta Transportation currently manages approximately 500 geohazard sites through the Geohazard Risk Management Program (GRMP). While the GRMP facilitates inventorying, inspecting and repairing the sites using risk-based prioritization, it does not allow for forecasting deterioration of these sites, nor effectively advocating for the needed funds to maintain the geotechnical inventory in the long term, thereby preserving the transportation system at the lowest overall cost.

Alberta Transportation's strategic vision for the GRMP is to transform it into a formalized Geotechnical Asset Management program, guided by leading practice in Transportation Asset Management, for achieving desired levels of service and risk reduction for geotechnical assets across the provincial highway network.

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