# Slope Instability Risk Management for State Roads Queensland, Australia

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ABSTRACT: Slope instability and landslides affecting natural slopes, road cuttings, embankments and retaining structures can result in traffic delays, major transport network disruptions, significant road infrastructure and property damage, injuries and even death to road users. In common with other Australian state and international road agencies, the Queensland Department of Transport and Main Roads (TMR) is taking a proactive approach to reducing risks to road users, infrastructure and property from slope instability along the state road network by developing and implementing effective risk management strategies.TMR is using a three stage strategy, a "Proactive, Prioritised Program", to identify potential slope instability, categories and priorities risks, and implement a prioritised program of works to effectively manage batter slopes and reduce risks from slope instability.

## 1 INTRODUCTION

### 1.1 *Outline*

Queensland Department of Transport and Main Roads (TMR) has implemented a simple three stage strategy to effectively manage its batter slopes and reduce the risk of slope instability for road users, its state road network asset, and related infrastructure or property. TMR's strategy is a "Proactive, Prioritised Program" which comprises:

**Stage 1** *Proactively* identify slope instability likely to affect the state controlled road network.

**Stage 2** Categorise and *Prioritise* the risks to road users and the network.

**Stage 3** Develop and implement a prioritised *Program* of works to reduce risks.

This paper:

- Outlines TMR's context for batter slope management along Queensland state roads.
- Describes the three stages of TMR's slope instability risk mitigation strategy.
- Describes TMR's decision matrix which is used as a guide to consistently plan and implement risk mitigation strategies for slopes based on the category of risk.

### 1.2 *Context*

The state of Queensland, Australia has a population of about 4,560,000 people widely dispersed over an area of about 1,852,642km$^2$, from sparsely settled communities in rural and remote areas to more densely settled communities along the east coast in regional towns and urban centres.

The climate is variable from monsoonal wet seasons in the north, warm temperate conditions along the coast and hot dry conditions inland. Cyclones and low pressure systems result in episodes of extreme wet and flooding conditions in different areas of the state.

TMR manages the state controlled road network which consists of about 34,000km of state road. The state controlled road network traverses about 540km of mountainous road terrain, 3,700km of rolling road terrain and 29,100km of level road terrain. The state controlled road network comprises about 20 percent of Queensland's total road network, yet carries 80 percent of state traffic.

As the asset manager, TMR has a strategic role in leading a safe and accessible transport system that contributes to the economic and social development and enhances the quality of life in Queensland.

One 'element' of the state road asset under TMR's jurisdiction is management of its Batter Slopes. The objective of the Batter Slope Management element is to facilitate effective management of batter slopes to achieve proactive risk reduction from slope instability and deliver safer roads for safer communities.

Slope instability investigation, analysis and mitigation design is typically carried out by experienced geotechnical professionals. Hence, responsibility for administering the batter slope management program lies with TMR's Geotechnical Section.

## 2 PROACTIVE IDENTIFICATION OF POTENTIAL SLOPE INSTABILITY (STAGE 1)

TMR's slope risk management strategy starts with an inventory to proactively identify potential unstable slopes that can affect the road network. Initially a desktop assessment is undertaken which includes consultation with road operators and assessment of historic slope instability. The desktop assessment considers road usage patterns, what types of failures have occurred, where, frequency, underlying geomorphology and terrain, existing hazards and factors influencing instability (eg impacts from severe weather events).

The results of the desktop assessment are used to target road sections for a Stage 1 inspection to gain an inventory of slopes and broadly categorise the potential *geotechnical* risk they pose to road users and/or other elements within the zone of influence (ie. Likely or unlikely). The types of slopes to be identified include road cut and embankment slopes, retaining structures, natural slopes (above and below) the road, and bridge abutments.

The Stage 1 inspection is conducted rapidly and based on a quick visual assessment and captures slope location (GPS position and road chainage), basic slope attributes (slope type, height, material, evidence of previous instability etc) and whether the slope has a likely potential of risk.

## 3 CATEGORISE AND PRIORITISE RISKS (STAGE 2)

In Stage 2, slopes with a 'likely' potential of instability identified during Stage 1 are targeted to visually assess their risks to road users, infrastructure and property within the zone of influence of landsliding at a particular point in time. TMR has adopted the slope risk assessment methodology from Road and Marine Services of New South Wales (NSW RMS) Guide to Slope Risk Analysis Version 4 (2014) for this purpose. Using this method risks are visually assessed on the basis of:

a) Likelihood of slope failure and
b) Consequence of slope failure.

Five indicators of risk as described in Table 1 are considered with each hazard or failure mechanism. The NSW RMS Guide provides matrices to then combine the five indicators of risk to determine the Assessed Risk Level (ARL) and other classification parameters (hazard classification, event magnitude and slope attribute score).

The visual inspection is initially carried out from the road, as well as above or below the road depending on site accessibility.

Table 1. Indicators of risk considered with each hazard or failure mechanism (After NSW RMS, 2014)

| *Risk Indicator* | *Description* |
|---|---|
| *Scale of Failure* | The potential volume of large slides or size of individual blocks |
| *Rate of Failure* | From extremely rapid failures with no warning to slow failures with sufficient time to take evasive action. |
| *Likelihood of Failure* | A visual assessment of detachment probability and probability of interaction with the risk element based on slope geometry, geomorphology, influencing factors or events, similar experience and history. |
| *Temporal Probability* | Probability of a person / vehicle being in the vicinity (measured as average annual daily traffic count per lane affected). |
| *Vulnerability* | The probability of a person or vehicle being impacted by or impacting on the hazard. |

The ratings assigned to each indicator are based on the judgment of an experienced and qualified geotechnical professional trained in the NSW RMS methodology, using varying amounts of information from visual assessment, geological and engineering analysis, data and matrices in the NSW RMS Guide.

The Assessed Risk Level is the key outcome from the risk assessment process and is used to categorise the risks from slope instability for each hazard on a scale of ARL1 (very high risk) to ARL 5 (very low risk). With consistent application of the risk assessment process, risks can be broadly ranked at a state network level to plan and prioritise risk mitigation strategies.

Within the ARL categories, hazard classification (which includes likelihood of occurrence) and road network priority classification (eg. traffic type, volume, alternative routes, network links and community access) will also be considered in TMR's prioritisation process for treatment, with additional consideration for potential impacts to other infrastructure and property within the zone of slope instability influence.

## 4 RISK MITIGATION (STAGE 3)

Based on the outcomes from the risk assessment and prioritisation process, some slopes may require action to manage or treat hazards to reduce the risks.

TMR has developed a matrix to assist decision makers in applying a consistent strategy to mitigate risks based on Assessed Risk Levels and accepted Australian national standards and practice for evaluating risk in terms of tolerable risk criteria. The following sections describe the decision matrix's development, presents the matrix as a guide to assist decision makers, and provides a framework to implement a prioritised program of works to manage and reduce slope instability risks.

## 4.1 *Evaluation of Risk*

Previous work by others has described tolerable risk criteria in terms of indicative annual probability of loss of life, and what probabilities may or may not be considered be tolerable or acceptable societal risks (AGS (2007d), Leroi et al.(2005), Locke (2004), ANCOLD (2003), Stewart et al.(2002), RTA (2001), AGS (2000), Finlay & Fell (1997)).

AGS (2007d) has distinguished between "tolerable risks" and "acceptable risks" as follows:

*Tolerable risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.*

*Acceptable risks are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless such measures are available at low cost in terms of money, time and effort.*

AGS (2007d) notes a number of organisations have adopted tolerable risk as the measure to gauge risk due to the benefits and cost of risk mitigation, and the costs to achieve acceptable risk levels often being high. Stewart et al. (2002) and Locke (2004) have related Assessed Risk Levels from potential slope instability to indicative probabilities of loss of life (see Table 2a). However, each ARL contains a range of indicative probabilities and is subject to uncertainty due to the inherent imprecision and variability of many parameters that are determined largely from visual observation and judgment used in the analysis(Stewart et al. (2002)).

## 4.2 *Decision Matrix for Strategic Risk Mitigation*

After consideration of published tolerable risk criteria (AGS, 2007d), accepted national standards and literature sources, TMR has developed a decision matrix for planning and implementing slope risk mitigation strategies in Queensland. The basis for TMR's decision matrix is shown in Tables2a to 2c and is intended to assist strategic decision-making for new and existing slopes based on risk category, and establish a basis for consistent interpretation of risk categories and resultant risk mitigation targets.

Based on TMR's decision matrix, an assessed level of risk ARL 1 to ARL 3 indicates a need for some form of risk mitigation. As indicated in Table 2b, generally any slope classified as ARL 1 or 2 should be remediated by appropriate stabilization methods to reduce the level of risk to ARL 3 or lower. Depending on scale, cost and societal considerations, there may be some cases where the ALARP "As low as reasonably practical" principle is adopted, however these slopes still require an appropriate risk management plan. Slopes classified as ARL 3 require further evaluation to determine the cost-benefit of treatment or risk management and as a minimum should undergo regular re-inspection.

Table 2a. TMR's Decision Matrix for Strategic Slope Risk Mitigation –Levels and Probability of Risk

| *ARL Category* | *Relative Risk Level* | *Probability of Risk (Individual loss of life)* |
|---|---|---|
| *ARL 1* | Very High Risk | $>10^{-3}$ /annum |
| ARL 2 | High Risk | $>10^{-4}$ but $\leq 10^{-3}$ /annum |
| ARL 3 | Medium Risk | $>10^{-5}$ but $\leq 10^{-4}$ /annum |
| ARL 4 | Low Risk | $>10^{-6}$ but $\leq 10^{-5}$ /annum |
| ARL 5 | Very Low Risk | $\leq 10^{-6}$ /annum |

Table 2b. TMR's Decision Matrix for Strategic Slope Risk Mitigation – Risk Tolerance

| *ARL Category* | *New Slope Construction* | *For an Existing Slope* |
|---|---|---|
| ARL 1 | Not tolerable | Generally regarded as not tolerable |
| ARL 2 | Not tolerable | May be tolerable in the short term, subject to closer examination |
| ARL 3 | Generally not tolerable. May be tolerable subject to cost - benefit analysis | Generally tolerable in the short to medium term. May be tolerable in the medium to long term depending on cost -benefit analysis and a site specific evaluation of acceptable risk. |
| ARL 4 | Tolerable<br>Target for new construction | Tolerable under most circumstances |
| ARL 5 | Tolerable | Tolerable |

Table 2c. TMR's Decision Matrix for Strategic Slope Risk Mitigation – Risk Management/Mitigation

| *ARL Category* | *Management Plan* | *Target Risk Mitigation Strategy* |
|---|---|---|
| ARL 1 | Required | Treatment or risk management to reduce risk to ARL 3 or lower. |
| ARL 2 | Required | Treatment or risk management to reduce risk to ARL 3 or lower. |
| ARL 3 | Required | For existing slopes, maintain at this level. Regular monitoring and evaluation for treatment and / or risk management. |
| ARL 4 | Not required | Maintain at this level. Re-assessment in 5 years or change in condition. Monitor by road patrols. |
| ARL 5 | Not required | |

### 4.3 *Planning a Prioritised Program of Risk Mitigation Activities*

From a state-wide prioritised list of high risk slopes, and with consideration of required risk mitigation strategies, options and available funding, a forward program of planned activities to manage and reduce risk is prepared annually. This is carried out for a geographical area by a group comprising the Batter Slope Element Leader, area and maintenance engineers, Geotechnical professionals and TMR asset investment analysts. From a forward and costed program, projects can be planned and implemented with a strategic focus and budget to manage and reduce risks from slope instability.

## 5 CONCLUDING REMARKS

Slope instability risk assessment, data collection and prioritised risk mitigation programs are ongoing activities in TMR, as risks will continue to evolve with ageing road networks, changing design standards and road user expectations, increasing traffic volumes, increasing development, funding challenges and severe weather events.

Slope instability risk management may be further complicated by slope failures with variable materials, uncertain parameters and complex processes. Even with a strategy and planned risk management activities, extreme weather events causing unexpected failures can occur in Queensland and are difficult to predict. Hence, TMR also has a guide for major slope failures that can be integrated with other emergency response plans.

TMR has adopted the NSW RMS Guide to Slope Risk Analysis as its basis for network level assessment of slope instability. From ARL and tolerable risk criteria, TMR has developed a decision matrix to assist its strategic prioritisation of slope risk mitigation.

The NSW RMS Guide requires thorough visual inspection and expert judgment by trained and experienced geotechnical practitioners, and consistent consideration of risk indicators as a demonstrable chain of reasoning and documentation of assumptions. Actual prediction or modelling of potential slope failures requires more detailed geotechnical investigation and slope instability analysis.

TMR's "Proactive, Prioritised Program" is a three stage network level strategy to manage the risk of slope instability along state controlled roads in Queensland, Australia, by development of prioritised programs of risk mitigation works to gain the most strategic risk reduction formal located funds. This strategy aims to deliver a key outcome of 'safer roads for safer communities'.

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