Standard

Geotechnical Risk Assessment and Hazard Management

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Preface

The Asset Standards Authority (ASA) is an independent unit within Transport for NSW (TfNSW) and is the network design and standards authority for defined NSW transport assets.

The ASA is responsible for developing engineering governance frameworks to support industry delivery in the assurance of design, safety, integrity, construction, and commissioning of transport assets for the whole asset life cycle. In order to achieve this, the ASA effectively discharges obligations as the authority for various technical, process, and planning matters across the asset life cycle.

The ASA collaborates with industry using stakeholder engagement activities to assist in achieving its mission. These activities help align the ASA to broader government expectations of making it clearer, simpler, and more attractive to do business within the NSW transport industry, allowing the supply chain to deliver safe, efficient, and competent transport services.

The ASA develops, maintains, controls, and publishes a suite of standards and other documentation for transport assets of TfNSW. Further, the ASA ensures that these standards are performance based to create opportunities for innovation and improve access to a broader competitive supply chain.

This document specifies the geotechnical risk assessment and hazard management requirements for geotechnical problem sites for the safety of rail operations and infrastructure. This includes people who are travelling in trains or located adjacent to the line, to railway infrastructure and operations, and to dwellings and properties adjacent to rail corridor.

The content of this standard is derived from RailCorp document TMC 401 Geotechnical Risk Assessment and Hazard Management Guidelines, Version 1.1 and the requirements of Asset Standards Authority publishing framework. The geotechnical risk assessment methodology and the hazard management of TMC 401 have been retained.

This document supersedes the existing RailCorp document TMC 401.

The changes made include the following:

- replacement of RailCorp organisational roles with those applicable to current ASA organisational content
- addition of definitions, abbreviations
- minor modifications / correction to Figure 1 and Figure 2 for clarity
- re-writing of the existing management requirements to be consistent with current ASA organisational context for clarity
- minor amendments to the text for clarity and improvement
- deleting of RailCorp safety risk management reference in Table 4 and in the text, RailCorp SMS likelihood descriptors in Table 3
- deleting the section 'competencies' and adding a general description under the management requirement
- conversion of the document to ASA format and style
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1. **Introduction**

This standard presents a risk assessment methodology to rank the geotechnical problems after identification, and the hazard management required for risk mitigation.

2. **Purpose**

The main purpose of this standard is to provide a geotechnical risk assessment model for assessing the potential risk arising from geotechnical problems and for managing the assessed risk in a consistent manner for the safety of rail operations and infrastructure.

2.1 **Scope**

This standard presents a qualitative assessment methodology to rank the risk from geotechnical problems to the safety of rail operations and infrastructure, and hazard management required to reduce the risk. This includes risk to people who are travelling in trains or located adjacent to rail lines, to railway infrastructure and operations, and to dwellings and properties adjacent to rail corridors.

This document does not cover the competency requirements for specified tasks.

The content of this standard derives from the pre-existing RailCorp document TMC 401 *Geotechnical Risk Assessment and Hazard Management Guidelines*.

It is possible the assessment methodology and hazard management presented in this document may not be an appropriate tool in some circumstances for a particular geotechnical risk site. In such cases site specific risk management strategy should be implemented.

2.2 **Application**

This standard is intended to be used by AEO geotechnical representatives experienced in risk assessment and geotechnical stability analysis. In addition, this standard provides requirements for the geotechnical hazard management to personnel who manage geotechnical assets.

3. **Reference documents**

Transport standards – as published on the ASA website

TMC 203 Track Inspection

T HR CI 12101 ST Geotechnical Problem Management
4. Terms and definitions

The following definitions apply in this document:

**AEO** is the Authorised Engineering Organisation responsible for maintenance of the network's civil assets

**AEO geotechnical representative** is an appropriately qualified and experienced geotechnical engineer with relevant competencies for geotechnical risk assessment, geotechnical design, construction and maintenance activities relating to geotechnical assets

**AEO maintenance representative** is an appropriately qualified and experienced representative of the AEO's civil maintenance organisation

**ASA** Asset Standards Authority

**EWS** Early warning system

**Protected Risk** Residual risk of a geotechnical problem site after imposition of risk mitigation actions to reduce the consequences of an event affecting the rail infrastructure

**Risk Site Register** A database containing geotechnical risk site information and maintenance schedules

**Site Supervisor** A qualified civil engineer or an appropriately experienced competent person for geotechnical repair works supervision

**TES** Track examination system

**TMP** Technical maintenance plan

**Unprotected Risk** Geotechnical risk of a site before application of risk controls

5. Geotechnical risk management plan

A flow chart for managing geotechnical risk is shown in Figure 1. This flowchart demonstrates where the risk assessment and hazard management processes fit in the geotechnical risk management plan for rail network.

The following sections describe in detail the components relating to geotechnical risk assessment and hazard management.
6. Management requirements

The AEO maintenance representative is responsible for the following:

- ensuring that geotechnical problem locations are managed by competent persons in accordance with this standard, T HR CI 12101 ST Geotechnical Problem Management, the relevant technical maintenance plans and service schedules
- managing routine inspections, special inspections by trained track staff, and assessments of geotechnical risk sites
- assigning AEO geotechnical representative to conduct risk site inspections, reviews, and risk assessments

Figure 1 - Geotechnical risk management plan
• managing repairs to geotechnical risk sites
• managing track safety whilst geotechnical risk exists
• managing the geotechnical risk site register

The AEO maintenance representative shall ensure the competencies and training requirements for staff carrying out various tasks described in this document.

The tasks may include:
• geotechnical risk site inspections and risk assessments by the AEO geotechnical representative
• surveillance inspections of risk sites by trained track staff
• design of geotechnical repairs
• repair works to risk sites
• certification of the track during or after geotechnical repairs

7. Geotechnical risk assessment

7.1 General

Risk assessment of geotechnical problem sites shall be carried out by the AEO geotechnical representative.

Assessment of a risk presented by a geotechnical problem site requires an assessment of both the likelihood of the event occurring and affecting the track or other infrastructure, and the expected consequences of that event.

Estimating the likelihood of a geotechnical problem (event) affecting the track requires both geotechnical expert evaluation of the ground conditions including the causes of failure associated with the particular site, and an estimation of the extent and degree of failure. The problem is considered in three stages:
• the likelihood of the event occurring
• the likelihood of the event affecting the track or other infrastructure
• the size of the event

Consideration is given to the possible benefit of buffer zones beside the track when evaluating rock falls from above the track and the expected rock fall size and trajectory. Situations of earth fill instability require an expert evaluation of the likelihood of the occurrence, the potential extent, and the rate of movement.

Figure 2 presents a flow chart setting out the assessment process.
7.2 Risk matrix

The interaction of two subjective assessments, likelihood and consequence, has been presented as a matrix in Appendix A.

This matrix is the same as that used in RailCorp document TMC 401 Geotechnical Risk Assessment and Hazard Management Guidelines, published in December 2008 and in use by railway geotechnical professionals since then. The risk ratings in the matrix are linked to the target actions in Table 4 and the hazard management in Table 5.

The risk matrix in Appendix A is only to be used to assess the geotechnical risks on NSW rail network.

Geotechnical risk is expressed in terms of a risk ranking between A and D.

A priority sub-ranking within rankings B- and C+ has been established because of the large number and variety of problems normally assessed in these rankings. The priorities set different target actions and hazard management requirements within rankings B- and C+. Refer to the tables in Appendix A and Appendix B.

For example, where assessed that there is a possible likelihood (F4) of an event occurring and affecting the track with major consequences (C3), sites are categorised as Risk Ranking B+, P1.

Table 4 in Appendix A presents target actions for geotechnical problem sites.

Without treatment, many problems will continue to deteriorate and, conversely, in times of prolonged dry weather or favourable conditions the risk to safety can be less.

Where the risk to safety results from deteriorating track conditions, estimation of consequences shall take into account the ability of maintenance resources to restore safe conditions. If the rate of deterioration exceeds the capacity of maintenance staff to restore safe conditions, the deterioration will continue and may produce a derailment potential. The likelihood of derailment and the consequences are therefore considered in determining a risk ranking. This assessment will require advice on maintenance resources and track / train dynamics from the relevant staff in infrastructure maintenance.
Figure 2 - Assessment of geotechnical risk to rail operation
8. Risk assessment procedure

8.1 General

The flow chart in Figure 2 sets out the process in assessing the risk due to a geotechnical problem. The following sections provide guidance in making an assessment. They are neither exhaustive nor definitive and the practitioner is required to use their own experience and knowledge for evaluating each likelihood assessment and the risk.

Similar procedures can be used for risk assessment of adjacent property.

Where the problem is observed to be extensive and presents a high risk to safety, it may be necessary to be more objective, and a quantitative risk assessment may be required. The same methodology for assessing the risk is followed with the use of more reliable information.

The assessment of geotechnical risk is to be initially considered without any hazard management in place. Hazard management and its impact on the risk will be considered independently.

8.2 Identification of geotechnical problem

A geotechnical problem that has been identified by following the risk management plan presented in Figure 1, shall be listed on the geotechnical risk site register. The geotechnical problem is either being assessed for the first time or is under review.

8.3 Type of geotechnical problem

The type of problem can be one of the following:

- unstable cutting or hillside producing a rock fall, rockslide, landslide, or mudslide problem
- unstable embankment or an embankment producing, or has potential to produce, track subsidence/movement, loss of track support, ballast washaway, or total collapse
- failing track formation producing poor track geometry
- foundation failure due to inadequate bearing capacity or excessive settlement

8.4 Mechanism of failure

It is important to have a good understanding of the mechanism of failure of the geotechnical problem before attempting to arrive at any likelihood assessments. Deduction of the mechanism of failure results from the findings of the site investigation, from site inspections, or from the experience and knowledge of the practitioner.

Where there are numerous individual problems within the one site it is necessary to evaluate them separately to determine the highest risk for the site or report them separately.

Table 1 provides some examples of mechanisms of failure.
Table 1 - Examples of mechanisms of failure

<table>
<thead>
<tr>
<th>Embankments</th>
<th>Cuttings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidence, creep</td>
<td>Rock slides</td>
</tr>
<tr>
<td>Sliding</td>
<td>Wedge, plane and topple failures</td>
</tr>
<tr>
<td>Collapse</td>
<td>Rolling rocks</td>
</tr>
<tr>
<td>Washaway</td>
<td>Landslides</td>
</tr>
<tr>
<td>-</td>
<td>Mudflows</td>
</tr>
</tbody>
</table>

Refer to T HR CI 12101 ST *Geotechnical Problem Management* for details of some example problems typically encountered in the rail environment.

8.5 Event

It is recommended that the likelihood of the event occurring is considered separately from the likelihood of the consequences before calculating risk.

Sections 8.6 to 8.9 refer only to the likelihood of the event occurring and affecting the track.

8.6 History of problem

To understand the potential for a failure and its consequences it is necessary to research the history of the site. Good questions to ask include the following:

- what evidence is there that warning signs of failure have been observed?
- what incidences have been reported and recorded by maintenance staff and over what period?
- what information is available from geotechnical monitoring (if it is in place)?
- what degree of the problem has previously been experienced at the site?

An understanding of likelihood of failure can be gained from the following type of information:

- number of rock falls per year
- amount of ground movement over particular periods, and type of movement (creep or shear)
- amount of maintenance effort required to provide a serviceable track
- correlation of events with factors such as rainfall

8.7 Condition of infrastructure

The condition of infrastructure influences the occurrence of an event, and therefore including this information allows a better assessment of likelihood. Infrastructure in good condition will have a lower likelihood of failure for the same mechanism than for a similar situation where the infrastructure is in poor condition. Table 2 gives a range of conditions that can influence the likelihood of an event.
### Table 2 - Examples of conditions of infrastructure

<table>
<thead>
<tr>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cuttings are clean with no vegetation</td>
<td>• Thick vegetation over rock cuttings, active tree root activity</td>
</tr>
<tr>
<td>• Cess and toe drains are clean and graded uniformly</td>
<td>• Cess drains blocked and ponding water</td>
</tr>
<tr>
<td>• Top drains are clear and intact and direct water to culverts</td>
<td>• Water ponding at embankment toe and/or top</td>
</tr>
<tr>
<td>• Cut off drains are in place for up hill seepage</td>
<td>• Top drains blocked or breached</td>
</tr>
<tr>
<td>• Well engineered fill</td>
<td>• No cut off drains and seepage from uphill is active</td>
</tr>
<tr>
<td>• Culvert capacity adequate without ponding for design storm</td>
<td>• End tipped fill</td>
</tr>
<tr>
<td>• Wide cess</td>
<td>• Ash embankment widened on the downstream side with clay fill</td>
</tr>
<tr>
<td></td>
<td>• Culvert not positioned correctly - not in the lowest part of the embankment</td>
</tr>
<tr>
<td></td>
<td>• Culvert inadequate and ponding on upstream occurs regularly</td>
</tr>
<tr>
<td></td>
<td>• High potential for blockage of culvert</td>
</tr>
<tr>
<td></td>
<td>• Excessive erosion of slopes</td>
</tr>
</tbody>
</table>

### 8.8 Likelihood of failure

After considering the information suggested in Section 8.3 to Section 8.7, make an assessment of the likelihood of failure.

### 8.9 Likelihood of failure and affecting the track

Having selected a likelihood of failure occurring, modified by the influence of the condition of the infrastructure, review this with regard to the likelihood of it adversely affecting the track. To do this, it is necessary to consider the site conditions and the mechanism of failure.

**Example**

There may be a small buffer zone beside the track and with other contributing factors, an assessment could be made that there was reduced chance that the rock fall would adversely affect the track. That is, an *almost certain* likelihood of an event occurring with a *possible* likelihood of an event affecting the track may equate to a *likely* likelihood of the event occurring and affecting the track.

It is also necessary to assess the likelihood for various degrees of impact to the track by asking the following questions:

- will the impact on the track be major or minor?
- where will the debris be likely to come to rest - on the track or beside the track?
- will the embankment failure undermine the track or only affect the batter slope?

If there is a reasonable expectation that the effects could include a major impact then it is necessary to assess all outcomes separately.
To calculate 'likelihood' quantitatively it would be advisable to use an Event Tree Analysis to include all possible outcomes with numerical values for likelihood of the event occurring over a nominated time frame.

### 8.10 Consequence

Having arrived at an assessment of the likelihood of the event occurring and affecting the track the following sections 8.11 to 8.21 assess the likelihood of death and serious injury from that event. It is necessary to look at the various types of outcome possible from the mechanism of failure.

#### 8.11 Track obstruction

This refers mostly to outcomes from cutting failures where the effect is debris on the track, which will obstruct traffic.

#### 8.12 Type of obstruction

When considering the impact of an obstruction on the track to track safety, it is necessary to be aware of the particular type of obstruction that each problem will produce. To make a realistic interpretation on the outcome of a train colliding with the obstruction it is essential to be reasonably confident of the manner of the collision. Consider the following features of the obstruction:

- single rock or scree
- shape and size of the rock
- what the debris consists of - rocks, colluvium, mud, and so on
- crushability of rock material

#### 8.13 Size and degree of obstruction

The outcome of a train colliding with an obstruction is also dependent on the magnitude of the obstruction and how much of the track is affected. Consider the following factors:

- size of debris mass and its spread over the track
- depth of material over the track

#### 8.14 Track defect from geotechnical problem

A track defect may be the result of embankment subsidence, slip, formation washout, or failure of track formation.
8.15 Type of defect
This may vary from unstable embankments, unstable slopes, bearing capacity failure of the track bed causing depression in one or both rails. A misalignment can also be a symptom of embankment subsidence or movement.

Loss of track support due to a collapse of the embankment or a washaway of ballast or fill or formation of sinkholes is considered under this issue.

8.16 Degree of defect
The degree of track defect will depend on the particular site and the failure mechanism. The history of the site will provide information about the rate of failure, and whether the track defect will occur suddenly or slowly due to creep.

For an unstable embankment or slope, the failure mechanism must be identified in order to determine the effect to the track support.

The impact on track safety will also depend on whether the failure will cause non-uniform subsidence (or twist) or a uniform depression in the track over a short or long distance, and whether the track becomes misaligned as a result. The background information should provide guidance on this issue.

8.17 Likelihood of derailment
Having considered all the information reviewed as per sections 8.10 to 8.16 relating to the impact of the event on the track an assessment of the likelihood of a derailment occurring is made.

8.18 Type of derailment
Having established that there is a likelihood of derailment occurring, before assessing the risk of death or serious injury, it is necessary to review the type of derailment that may occur.

8.18.1 Track obstruction
The nature of the obstruction will contribute to the manner of the derailment and the likelihood that the derailment will almost certainly or highly likely involve the leading locomotive or carriage.

8.18.2 Track defects
A derailment resulting from a track defect, caused by a geotechnical event, is highly likely to involve a trailing wagon or carriage.
8.18.3 Manner of derailment

Having understood the type of derailment, it is also necessary to consider the manner or behaviour of the train after the derailment. This will involve considering the terrain around the site and the directions of train travel if double track. Some possible outcomes are:

- train or carriage stays upright and comes to rest
- train collides with a more substantial obstruction (bridge, tunnel portal, and so forth) and jack knifes
- train careers off the track and down an embankment, onto private property, over steep incline, and so forth
- the train crosses onto another track
- the train collides with an oncoming train
- the train overturns and slides to rest, etc

It is necessary to consider which of the above are most appropriate to the particular site, and the likelihood of each outcome occurring.

8.19 Extent of the consequences from the derailment

Having considered the possible derailment outcomes and the likelihood of each it is necessary to assess the likelihood of death or serious injury from each outcome.

8.20 Rock fall during train passage

From the history and mechanisms at the site, it is possible that the most dangerous mechanism will involve rock fall during train passage. This will involve rocks of all sizes and the consequence will depend on their trajectory across the track. For example, if small rocks are projected across the cutting at cabin height there is a chance of striking a person.

8.21 Likelihood of rock striking a train

Determining the likelihood of rocks striking a train requires some history of rock fall or observation of debris around the site, and information on the frequency of train passages and exposure time in the cutting.

8.22 Extent of the consequences from rock fall

It is necessary to have information on the type of trains on the line as the likelihood of death or serious injury will be higher for passenger trains. The frequency of train passage is also required to assess the consequence and operations.
8.23 Extent of the consequences from the event

Decide on the extent of the consequences ranging from disastrous to negligible, as defined in the risk matrix in Appendix A.

8.24 Risk of death, serious injury from geotechnical event

Finally, a risk ranking is determined from the matrix in Appendix A, using the 'Likelihood' of the geotechnical event affecting the track and the 'Consequence' from that event affecting the track as determined above.

9. Hazard management

Hazard management can effectively reduce the geotechnical risk facing the rail system by reducing the consequence rather than eliminating the problem where the cost or practicabilities of eliminating the hazard are prohibitive. This can be achieved by imposing operational limitations or by increasing maintenance.

The assessment of the reduced risk to rail operations due to hazard management is shown as Protected Risk by acknowledging the benefit of:

- speed limits for trains
- early warning systems
- regular maintenance activity
- increased surveillance inspections
- geotechnical instrumentation and monitoring

Where relevant, the use of 'protection' measures such as train speed limits or early warning systems may reduce the assessed Unprotected Risk to a safer Protected Risk by reducing the consequences of an event affecting the track. Such protection will not change the likelihood of the event occurring. For example, in the risk assessment matrix in Appendix A, an Unprotected Risk rank of A (F6:C3 in matrix) may be reduced to a Protected Risk rank of B+ (F6:C2 in matrix) because an imposed train speed limit has reduced the consequences from C3, Major to C2, Minor (the likelihood remaining at F6, Almost Certain). The risk ranking in this document generally refers to the Protected Risk.

Surveillance is an important hazard management tool as it can give warning of deterioration of a geotechnical problem site, or identify new problems. However, depending on the individual site and the level of surveillance, it may not always be relied on as a protection measure.

Appendix B contains definitions of the procedures and surveillance inspections requirements of geotechnical problem sites. The critical features to be checked during inspections are presented and Table 5 provides a flexible system to vary surveillance to suit the current situation.
The Table 5 provides the minimum levels of surveillance requirements relating to the risk ranking. For the bulk of geotechnical problems (Rank C+, D) a level of surveillance provided by the track examination system (T) is sufficient. However, for sites ranked as Rank B- or higher, more frequent inspections with greater detail are needed. Sites assessed as Rank ‘B-, P1’ require as a minimum, monthly detailed inspections during the track patrol, and for higher rankings, more frequent detailed inspections, or full time monitoring.

**Speed limits** are imposed by the AEO maintenance representative or recommended by the AEO geotechnical representative when it is recognised that conditions would be unsafe for normal speeds, or to reduce the consequences due to a geotechnical event. Speed limits are only a temporary measure as they have a direct influence on operating reliability.

**Early Warning Systems** are installed to provide warning of ground movement and/or rockfalls that would impact on safe operating conditions. A variety of systems exist, some of which are connected to the signalling system to stop trains, while others provide a warning to train control. The intention is to give sufficient warning to prevent the running of trains over unsafe track or to provide warning to adjacent property owners.

**Regular maintenance** of some geotechnical problem sites such as drainage improvements may reduce the likelihood of failure while other activities such as fettling are related to the reduction of the severity of the consequences.

All risk sites shall be reviewed by the AEO geotechnical representative every 12 months. For sites with rank ‘B-, P2’ or higher, the requirement is every 6 months or less.

Table 4 of Appendix A also contains target actions for geotechnical problem sites.

### 10. Repairs to geotechnical sites

Table 4 of Appendix A contains recommended timing of remedial works to geotechnical problems.

Design of geotechnical repairs shall be carried out by the AEO geotechnical representative.

During the construction of the remedial works to geotechnical problems, the exposed geotechnical conditions should be recorded and assessed by geotechnical experts to confirm the proposed design and to make modifications if necessary.

The design of repairs to geotechnical problems is based on as thorough an investigation as the site conditions and cost permits. The analysis and design is therefore based on the best ‘model’ possible and may not upon actual conditions.

It is therefore important to record all the information gained from the exposure of subsurface conditions by the excavations or borings associated with construction. It is possible then to modify construction, if necessary, where a more complete picture of the geotechnical problem is gained, that would suggest changes.
Post construction monitoring is also necessary to evaluate the effectiveness of the design and construction in correcting the geotechnical problem.

Appendix C sets out guidelines for the site supervision and recording repairs to geotechnical problems.
Appendix A – Risk assessment matrix and ranking

A.1 Geotechnical description of risk ranking

(Examples are not definitive and depend on individual risk assessment.)

A. UNACCEPTABLE

Track is impassable because of a geotechnical event. Traffic is stopped (unless hazard management measures are suitable) due to a geotechnical event which would be anticipated to result in loss of life being imminent and the situation is too dangerous to allow trains to pass.

Example 1 – A high embankment constructed on sidefill. The failure mechanism identified is a slide, which could occur rapidly, taking the track and leaving it unsupported. Track maintenance has little impact in reducing risk.

Example 2 – A high narrow cutting consisting of rock. This cutting has been identified as having potential failure mechanisms, which could produce large boulders that could crush a train or cause serious impact.

B. UNDESIRABLE

Safety action or hazard management is necessary for problems identified as undesirable, to reduce the likelihood of the event occurring or the consequences of that event. Such safety action, which includes maintenance, speed limits, and surveillance may effectively reduce the risk provided the action is continued.

Example 1 - A cutting consisting of weathered rock, which has been identified as a potential failure onto the track, into which the train might plough and become derailed.

Example 2 – A moderately high embankment constructed on gently sloping ground, with a failure mechanism identified as slow or comprising small increments, and the track can be maintained. Lack of maintenance would lead to derailment condition.

C. TOLERABLE

A low risk problem has been identified and (if remedial work incomplete) is being monitored for any deterioration to a higher risk.

Example 1 - A rock cutting that has been identified as potentially failing, or has failed and debris from the failure falls clear of the line.

Example 2 - An embankment constructed on gently sloping ground that is experiencing instability of the slope face, and which only affects an access road or embankment shoulder with no affects to the track geometry.

D. BROADLY ACCEPTABLE

Problem has been rectified and is being monitored for effectiveness of remedial work, or very low risk problem identified and is being monitored for any deterioration to a higher risk.
Table 3 - Risk assessment matrix - geotechnical problems

<table>
<thead>
<tr>
<th>Consequence</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 10 fatalities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disastrous</td>
<td>B-, P1</td>
<td></td>
<td>B+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catastrophic</td>
<td>C+, P1</td>
<td>B-, P1</td>
<td>B+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical</td>
<td>C-</td>
<td>C+, P1</td>
<td>B-, P1</td>
<td>B+</td>
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<td></td>
</tr>
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<td>Major</td>
<td>D</td>
<td>C-</td>
<td>C+, P1</td>
<td>B-, P1</td>
<td>B+</td>
<td></td>
</tr>
<tr>
<td>Minor</td>
<td>D</td>
<td>D</td>
<td>C-</td>
<td>C+, P2</td>
<td>B-, P2</td>
<td>B+</td>
</tr>
<tr>
<td>Illness, first aid treatment or injury not requiring treatment</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>C-</td>
<td>C+, P2</td>
<td>B-, P2</td>
</tr>
</tbody>
</table>

P1 and P2 = Priority for B- and C+

Safety action reduces the risk by reducing the consequence of the event affecting the track. The likelihood of event affecting the track is assessed from a visual inspection of the site and taking into account past performance.
Read Table 4 below in conjunction with Table 5 - Hazard management of geotechnical problem sites.

**Table 4 - Target actions for geotechnical problem sites**

<table>
<thead>
<tr>
<th>Risk Ranking (&amp; Priority)</th>
<th>Target actions for geotechnical problem sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Unacceptable (Extreme)</td>
<td>All necessary steps should be taken to further control the hazard. Track closed. Remedial works shall be immediately undertaken to eliminate possibility of an imminent geotechnical event, which is too dangerous to allow train passage or to restore track to service (where track is impassable due to geotechnical event).</td>
</tr>
<tr>
<td>B+ Undesirable (High)</td>
<td>Additional control measures should be sought and evaluated to assess their reasonable practicality and B+ hazards are considered to be on the verge of being unacceptable and shall be given immediate priority. Hazard management or safety action is immediately necessary to reduce the consequences of geotechnical event. Such action, which includes speed limits, maintenance and surveillance, may effectively reduce the risk provided the action is continued. Remedial works should be undertaken as soon as possible. Emergency possessions may be needed for remedial works depending on severity of problem (as assessed by the AEO geotechnical representative) or if hazard management / safety action is unsuitable. Target action is to remove / reduce this risk within 1 month of identification or sooner.</td>
</tr>
<tr>
<td>B-, P1 Undesirable (High)</td>
<td>Additional control measures should be sought and evaluated to assess their reasonable practicality. During rain, hazard management or safety action, may be necessary to reduce the consequences of geotechnical event. Such action, which includes speed limits, maintenance and surveillance, may effectively reduce the risk when applied. Remedial works should be undertaken at next planned possession if hazard management / safety action is unsuitable or the following possession. Notional target action is to remove / reduce this risk within 6 months of identification.</td>
</tr>
<tr>
<td>B-, P2 Undesirable (High)</td>
<td>Additional control measures should be sought and evaluated to assess their reasonable practicality. Monitoring (surveillance) should be carried out as per Table 5 to ascertain if geotechnical problem has deteriorated. Remedial works should be planned to be undertaken at a reasonably practicable time. Notional target action is to remove / reduce this risk within 12 months of identification.</td>
</tr>
<tr>
<td>Risk Ranking (&amp; Priority)</td>
<td>Target actions for geotechnical problem sites</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>C+, P1</td>
<td>Tolerable only if risk reduction is impractical or if its cost is grossly disproportionate to improvement gained and additional control measures should be sought if a significant net benefit in doing so can be demonstrated and / or there is an additional measure which is recognised as good practice in other relevant railways. Monitoring (surveillance) should be carried out as per Table 5 to ascertain if the geotechnical problem has deteriorated. Remedial works could be carried out at the same time as works to higher ranked instability features in the same area. The notional target action is to remove / reduce this risk within 18 months of identification.</td>
</tr>
<tr>
<td>C+, P2</td>
<td>Tolerable only if risk reduction is impractical or if its cost is grossly disproportionate to improvement gained and additional control measures should be sought if a significant net benefit in doing so can be demonstrated and / or there is an additional measure which is recognised as good practice in other relevant railways. Monitoring (surveillance) should be carried out as per Table 5 to ascertain if geotechnical problem has deteriorated. Remedial works could be carried out at the same time as works to higher ranked instability features if in the same area and if practicable. The notional target action is to remove / reduce this risk within 2 years of identification.</td>
</tr>
<tr>
<td>C-</td>
<td>Tolerable only if risk reduction is impractical or if its cost is grossly disproportionate to improvement gained and additional control measures should be sought if a significant net benefit in doing so can be demonstrated and / or there is an additional measure which is recognised as good practice in other relevant railways. Monitoring (surveillance) should be carried out as per Table 5 to ascertain if geotechnical problem has deteriorated. Remedial works could be carried out at the same time as works to higher ranked instability features if in the same area and if practicable.</td>
</tr>
<tr>
<td>D</td>
<td>Control measures should be subject to continuous monitoring. Monitoring (surveillance) should be carried out as per Table 5 to ascertain if geotechnical problem has deteriorated. Possible remedial works not imperative at this stage.</td>
</tr>
</tbody>
</table>
Appendix B – Hazard management of geotechnical problem sites

B.1 Surveillance inspection of geotechnical problem sites

The following features form a checklist for inspecting a site. Those which are relevant to a particular problem are to be noted, particularly for changes in condition between inspection visits.

A written report shall be prepared for each inspection. Make comments for each site. Sign and date the inspection record.

These reports are to be presented to the AEO maintenance representative immediately.

Refer T HR CI 12101 ST Geotechnical Problem Management for guidelines of recognising geotechnical problems.

B.1.1 Embankments and sidefills (slip problems)

Typical items to check:

- change in track alignment / superelevation
- tension cracks in the ground surface on the downhill shoulder or access road
- changes in width of such cracks
- dips in shoulder / access road
- loss of ballast shoulder
- bulges / slumps in slope or toe
- leaning structures (overhead wiring structures, signals, power poles)
- any seepage from slope, toe
- erosion of embankment
- vegetation - areas of unusual lush green vegetation
- cess drainage (clear or otherwise, water ponding)
- culvert condition (clear or otherwise)
- subsurface drainage (where applicable) - is water running?
B.1.2 Cuttings (rock falls)

Typical items to check:

- any recent rock falls or spoil onto track / cess drain, note size and origin
- recent rock falls onto bench areas or behind catch fences
- isolated or partially supported blocks of rock, due to cracks or joints
- overhanging or undercut rock
- apparent movement of prominent rock wedges / blocks
- widening of cracks
- condition of any nominated area of known instability
- excessive seepage / water flows
- damage to rock netting, catch fences
- damage to repairs, e.g. damaged shotcrete
- slumping and / or leaning trees above cutting
- tree roots visible in rock joints, excessive vegetation on cutting face
- rock trapped behind vegetation

B.1.3 Formation problems

Typical items to check:

- track depressions, lateral movement
- mud pumping
- ballast attrition
- heaves in the track shoulder / bulge in cess
- water in cess
- sinkhole
B.1.4 Notes for features for inspection checklist

The following are notes for the above sections:

- the inspections are an integral part of the safety management system of the railway and are distinctly separate from the route track patrol (T). Each site shall be inspected for the geotechnical features relevant for that site
- where applicable, the AEO geotechnical representative shall issue relevant, site-specific guidelines for inspections by track patrol staff. These guidelines may include descriptions of specific features and may include photographs of those features
- personnel with training in the geotechnical processes shall carry out the inspections on a regular basis with regular supervision
- an inspection register shall be maintained and each visit discussed with the nominated supervisor
- where any early warning system exists at a site, it shall be read and recorded
### B.2 Hazard management

The Table 5 below shows the hazard management requirements for geotechnical problem sites.

**Table 5 - Hazard management of geotechnical problem sites**

<table>
<thead>
<tr>
<th>Risk ranking</th>
<th>EWS Req’d</th>
<th>Surveillance</th>
<th>Speed limit</th>
<th>Surveillance</th>
<th>Speed limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wet</td>
<td>Dry</td>
<td>Wet</td>
<td>Dry</td>
</tr>
<tr>
<td>A</td>
<td>TC</td>
<td>TC or S4</td>
<td>TC</td>
<td>TC or Yes</td>
<td>TC</td>
</tr>
<tr>
<td>B+</td>
<td>Yes</td>
<td>S3</td>
<td>S2*</td>
<td>Yes</td>
<td>S2</td>
</tr>
<tr>
<td>B-, P1</td>
<td>Yes*</td>
<td>S2*</td>
<td>S1</td>
<td>Yes*</td>
<td>S1</td>
</tr>
<tr>
<td>B-, P2</td>
<td>Optional</td>
<td>S1</td>
<td>T</td>
<td>No</td>
<td>T</td>
</tr>
<tr>
<td>C+, P1</td>
<td>Optional</td>
<td>S1*</td>
<td>T</td>
<td>No</td>
<td>T</td>
</tr>
<tr>
<td>C+, P2</td>
<td>Optional</td>
<td>T</td>
<td>T</td>
<td>No</td>
<td>T</td>
</tr>
<tr>
<td>C-</td>
<td>Optional</td>
<td>T</td>
<td>T</td>
<td>No</td>
<td>T</td>
</tr>
<tr>
<td>D</td>
<td>No</td>
<td>T</td>
<td>T</td>
<td>No</td>
<td>-</td>
</tr>
</tbody>
</table>
Table legend

Without / with EWS Refers to cuttings and slips where an EWS is not / is installed

EWS Early warning system

Wet Periods of heavy rain or prolonged wet weather, as determined by the AEO maintenance representative.

Dry Prolonged dry weather, as determined by the AEO maintenance representative.

T, S Minimum surveillance levels as defined below

* Geotechnical requirements only, where site history suggests caution, and because of deteriorating site conditions. If not required, go to next lower level of surveillance (or speed limit not required)

Yes / No Speed limit or EWS required / not required

TC Track closed

Surveillance levels

(T is lowest level, S4 is highest level)

T Inspection under track examination system (TES) by trained track staff and annual review by the AEO geotechnical representative.

S1 Monthly walkover inspections during routine track patrol by trained track staff or more frequently as dictated by site conditions and weather, and six-monthly review by the AEO geotechnical representative.

S2 Twice per week inspections by trained track staff with site specific guidelines because of deteriorating site conditions and / or heavy rain, and six-monthly review by the AEO geotechnical representative.

S3 Daily surveillance by trained track staff with site-specific guidelines, and monthly review by the AEO geotechnical representative.

S4 Presence by track staff with site-specific guidelines prior to and during passage of trains, and weekly review by the AEO geotechnical representative.

Trained track staff means staff trained in recognising geotechnical problems – refer to T HR CI 12101 ST Geotechnical Problem Management.

Hazard management procedures above are to be instigated, but may change from the above if geotechnical advice on the specific site recommends a change.
Site reviews (inspections) by AEO geotechnical representative will be carried out at request of the AEO maintenance representative.
Appendix C – Site supervision and repair works

C.1 Repairs to geotechnical problems

C.1.1 Site supervision and recording

In regard to site supervision and recording, key points include the following:

- works should be adequately defined prior to commencement
- supervision is necessary because of variations in subsurface materials
- decisions made on site to alter the design without informed advice may jeopardise success of remedial works
- the Supervisor must have an appreciation of the purpose of the work
- accurate recording of work done is necessary to:
  - review accuracy of geotechnical model
  - plan for future remedial work by ensuring that a treated individual instability feature is removed from a list of numerous features
  - understand what additional work is necessary if further problems occur
  - review whether work was carried out according to the design or whether it achieved the objective
- if continuous supervision is not possible with staff available, qualified staff should visit the site periodically when work involves activities critical to the safety of the site and stability of the final solution. Guidelines for information necessary to ensure this are set out in section C.2

C.2 Earthworks site supervision

C.2.1 Geotechnical problems (embankments)

Key points to note during work include the following:

- maximum depth of any excavation - depth below rail to be measured and recorded
- date of measurement
- location of excavation, that is, distance from rail and distance along rail from a known point
- material visible in sides of excavation and in embankment, including the following details:
  - peculiar features (take photographs if possible)
- water, including source and flow
- ash
- spalls
- vegetation
- colour of material
- presence of top soil

- material placed in excavation, including the following details:
  - type
  - rock
  - spall
  - fabric
  - treatment, compaction, method of placement
  - level of each type below rail, and extent along and away from track

- levels and grade of subsoil drains

### C.2.2 Geotechnical problems (cuttings)

Key points to note during work include the following:

- type of material, soil/rock type
- discontinuities in rock
- additional defects encountered
- treatment of defects, e.g. shotcreting, rockbolting, rocknetting,
- rockbolt/anchor details and installed locations

Record and file the above information with the infrastructure maintenance staff and AEO geotechnical representative.