Planning and design

This part of the guide provides guidance for designing safety into mine and quarry operations. It describes in detail how to plan excavations, tips, ponds, dams, roads, and vehicle operating areas.
IN THIS SECTION:

3.1 Terminology
3.2 Appraisal of ground or strata instability principal hazard
3.3 Ground or strata instability principal hazard management plan (PHMP)
3.4 Geotechnical assessment
3.5 Slope design
3.6 Ground support and reinforcement systems
Planning for excavations requires a good understanding of ground conditions, and determining ways in which potential ground failure could be avoided. A systematic approach to managing ground instability is very important.

This section describes:

- how to identify and manage hazards from unstable ground
- the role of geotechnical assessments
- how to design safe slopes
- how to stabilise and support slopes.

The potential impacts of unplanned and uncontrolled ground movement are:

- Safety – Loss of life or injury to those working at or visiting the site.
- Social – Loss of income and workforce confidence, minimised corporate credibility, and increased liability.
- Financial and economic – Disruptions to operations, product or equipment losses, increased stripping and clean-up costs, and reduced access to markets.
- Environmental – Collapse of or damage to nearby infrastructure, interference with natural drainage and damage to surrounding land, natural habitats, wildlife or conservation initiatives and programmes.

Safely developing a mine or quarry requires assessment of the deposit and the factors that will affect ground stability including:

- the dip and strike
- bedding planes
- faulting
- folding
- other geological characteristics.

A systematic approach to ground stability requires a good understanding of ground conditions before operations start. Slope designs should be suitable for the ground conditions and, where necessary, include the design and implementation of ground support or reinforcement. The ongoing maintenance of supports and continuous monitoring for any indication of movement or potential for failure are also important components of a systematic approach.

Refer to Section 7 for more information on controlling ground stability.

### 3.1 TERMINOLOGY

Slopes are generally designed as a series of batters separated by benches, which are provided at predefined vertical height intervals (see Figure 2).

![Slope design terminology](Figure 2: Slope design terminology)

Access to an excavation can be by a road or ramp that may spiral around, or be located on one side of the excavation with switchbacks at each end. A succession of batters between two access ramp sections (or between a ramp section and the floor or crest) is defined as the inter-ramp slope. The inter-ramp slope angle is always flatter than the batter angle in that slope. The full height of a slope, from the toe to the crest, comprising several batters separated by benches (and access road sections if the road is on that slope) is the overall slope (see Figure 3).
of any such failure. The probability of such a failure actually happening is not relevant in this context. The consequences depend on the likely scale of the failure (that is, the size of the failure and the area affected by it) and whether people are likely to be fatally injured.

For other surface operations (ie quarries and alluvials) an appraisal of the operation must also be done by a competent person to determine whether a geotechnical assessment is required.

As a guide:

> Simple operations (eg shallow depth, soft material with faces less than 3.5 m, or competent rock with faces less than 15 m) require a geotechnical appraisal by a competent person to determine that the face design is safe, adequate benching is in place, and confirm to the operator that a geotechnical assessment is not required. Assessments should be in writing, dated and signed with a review period established.

> Complex operations (eg individual faces exceeding 15 m, overall excavation depth exceeding 30 m, fractured rock, disturbed geological structure) require a geotechnical assessment by a competent person.

A geotechnical assessment should be completed where:

> The height of any individual face is more than 15 m.

> In the case of ‘soils and very weak rock’ where the height of any part of an excavation is more than 3.5 metres and the overall slope angle is steeper than 2 horizontal to 1 vertical (27° to the horizontal) (see Figure 4).

> The bottom of the excavation is more than 30 metres below any surrounding land within 30 metres of the edge of the excavation (that is, the excavation is more than 30 metres deep, allowing for any nearby higher ground) (see Figure 5).
Irrespective of the excavation face height, depth or angle there are factors that mean there could be a principal hazard. An example could be fractured rock mass or geological discontinuities (poor rock mass quality) or the location or proximity of a tip.

In the case of ‘stronger rock’, and well-cemented gravels, a geotechnical assessment should be carried out where the overall:
- height of any adequately benched slope, from toe to crest, is between 15 m–30 m
- slope angle is steeper than one horizontal to one vertical ($45^\circ$ to the horizontal)

(see Figure 5).

Following the identification of ground or strata instability as a principal hazard, the SSE must ensure a geotechnical assessment is completed by a competent person. This must determine the level of ground or strata support required to safely conduct the mining operation.

A risk assessment must be completed for the ground or strata instability principal hazard. A description of how the risk assessment will be conducted and the results of the risk assessment must be included in the PHMP.

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3 The Regulations, regulation 71 (1)
4 The Regulations, regulations 68 (b) and (c)
The definition of ‘soils and very weak rock’ and ‘stronger rock’ is provided in Table 1 below.

### Soils and very weak rock

As defined by the NZ Geotechnical Society Incorporated Field Description of Soil Analysis Guideline (Dec 2005) Table 3.5 Rock Strength Terms being:

<table>
<thead>
<tr>
<th>Term</th>
<th>Field identification of specimen</th>
<th>Unconfined uniaxial compressive strength $q_u$ (MPa)</th>
<th>Point load strength $I_{50(50)}$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very weak</td>
<td>Crumbles under firm blows with point of geological hammer. Can be peeled by a pocket knife</td>
<td>1 – 5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Extremely weak (also needs additional description in soil terminology)</td>
<td>Indented by thumbnail nail or other lesser strength terms used for soils</td>
<td>&lt;1</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** No correlation is implied between $q_u$ and $I_{50(50)}$

### Stronger rock

As defined by the NZ Geotechnical Society Incorporated Field Description of Soil Analysis Guideline (Dec 2005) Table 3.5 Rock Strength Terms being:

<table>
<thead>
<tr>
<th>Term</th>
<th>Field identification of specimen</th>
<th>Unconfined uniaxial compressive strength $q_u$ (MPa)</th>
<th>Point load strength $I_{50(50)}$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely strong</td>
<td>Can only be chipped with geological hammer</td>
<td>&gt;250</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Very strong</td>
<td>Requires many blows of geological hammer to break it</td>
<td>100 – 250</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Strong</td>
<td>Requires more than one blow of geological hammer to fracture it</td>
<td>50 – 100</td>
<td>2 – 5</td>
</tr>
<tr>
<td>Moderately strong</td>
<td>Cannot be scraped or peeled with a pocket knife. Can be fractured with single firm blow of geological hammer</td>
<td>20 – 50</td>
<td>1 – 2</td>
</tr>
<tr>
<td>Weak</td>
<td>Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow with point of geological hammer</td>
<td>5 – 20</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

**Note:** No correlation is implied between $q_u$ and $I_{50(50)}$

*Table 1: Definition of very weak rock or soils and weak rock or stronger rock*
Table 2 shows questions that could be considered during a risk assessment completed in respect of ground instability.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONSIDERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope type</td>
<td>Active or inactive</td>
</tr>
<tr>
<td>Slope geometry</td>
<td>Overall slope height, slope angle, bench height, bench slope angle, bench width</td>
</tr>
<tr>
<td>Slope material characteristics (including alteration grade)</td>
<td>Rock or soil, structurally controlled, variable alteration or materials present, material or discontinuity shear strength parameters</td>
</tr>
<tr>
<td>Proximity of existing structures</td>
<td>Property or services adjacent to both crest and toe of slope, both external and located on site</td>
</tr>
<tr>
<td>Proximity of workers</td>
<td>Vulnerability, location relative to potential failure</td>
</tr>
<tr>
<td>Proximity of general public</td>
<td>Proximity of public access, roads, footpaths, walkways and so on</td>
</tr>
<tr>
<td>Failure mechanism</td>
<td>Rockfall, planar, wedge, toppling, rotational, flow, travel distance</td>
</tr>
<tr>
<td>Speed of failure</td>
<td>Rapid (flows, rockfall), slow (rotational), very slow (rotational)</td>
</tr>
<tr>
<td>Water (surface water and groundwater)</td>
<td>Visible signs of seepage or discharge, prevention of detrimental effects by effective surface water management</td>
</tr>
<tr>
<td>Past history of failure</td>
<td>History of instability (type, location and so on), visible signs of active or previous failure (bulging of slope surfaces and so on)</td>
</tr>
<tr>
<td>Existing remedial measures</td>
<td>Bolting, regrading, pumping (de-watering)</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Extensometers, piezometers, closure meters, EDM targets, radar</td>
</tr>
<tr>
<td>Seismic history</td>
<td>Whether the region is seismically active</td>
</tr>
<tr>
<td>Operating parameters</td>
<td>Exposure time of workers (shift), excavation method, associated equipment (vehicle) exposure, effects of poor blasting</td>
</tr>
</tbody>
</table>

Table 2: Key questions for risk assessment

### 3.3 GROUND OR STRATA INSTABILITY PRINCIPAL HAZARD MANAGEMENT PLAN (PHMP)

Where an appraisal has identified a principal hazard, the SSE must ensure there is a PHMP for the principal hazard₅.

The ground or strata instability PHMP must contain information detailed in regulations 68 and 71 of the Regulations. In summary, regulation 71 requires the PHMP to include:

> when and how ground failure may occur and how it can be avoided
> suitable ground control methods, including continuous modelling, testing and updating
> appropriate equipment and procedures for monitoring, recording, interpreting and analysing data about seismic activity
> collection, analysis and interpretation of relevant geotechnical data

₅ The Regulations, regulation 66 (1) (b)
how to maintain ground support integrity including replacement of defective supports
> allowance for higher standards of support to be installed than that required by the PHMP.

The ground or strata instability PHMP should be developed in the context of the whole HSMS and not in isolation. This will ensure gaps and overlaps are identified and used in the implementing of suitable controls for ground or strata instability.

For more detailed information on the content of the PHMP, and its relationship with other management and controls plans, processes and procedures see WorkSafe’s Guidance for a Hazard Management System for Mines and Developing a Ground or Strata Instability Principal Hazard Management Plan.

3.4 GEOTECHNICAL ASSESSMENT

Geotechnical assessments must be carried out by a competent person.

Geotechnical assessment of ground conditions is critical to developing a comprehensive PHMP, where applicable. The data collected during the geotechnical assessment underpins:
> slope design and its stability
> the implementation of a suitable support system (where required)
> the ongoing monitoring requirements suitable to the size and scale of the design.

The geotechnical assessment will provide an indication of the risk of failure of a particular slope. This normally involves application of a factor of safety calculation but may include more extensive probabilistic analysis. For more detailed information on factor of safety (FOS) and probability of failure (POF), see section 3.5.1.

The geotechnical assessment may include:
> field data collection
> formulation of a geotechnical model
> slope design
> design, control and monitoring of blasting
> design, installation and quality control of rock support
> design of suitable monitoring systems.

Factors that may be considered during the geotechnical assessment include:
> possible seismic (either natural or induced) or geothermal activity
> previously excavated or abandoned workings
> subsidence or settlement (either controlled or through strain)
> drainage patterns, groundwater regimes, water inflow and dewatering procedures
> equipment and procedures used for scaling
> effect of time and oxidation on rock support and stability.

3.4.1 FIELD DATA COLLECTION

Field data collection is the process of obtaining relevant information which might affect the design, construction and performance of excavations.

The information collected could include:
> site history
> topography and geomorphology
> local climate
> hydrogeology and drainage
> physical geology and geologic structure
> lithology and rock mass properties.

Data collection should always be carried out by a competent person (i.e., a geologist, engineering geologist or geotechnical engineer) or a properly trained geotechnician under the supervision of an engineering geologist or geotechnical engineer.

More information on field data collection can be found in Appendix C: Field Data Collection.
3.4.2 FORMULATION OF A GEOTECHNICAL MODEL

The geotechnical assessment should address or include:

> An assessment of the geological features of the deposit, including
  - the strength of the rock mass,
  - hydrogeology,
  - the orientation of geological structure,
  - external influences.

> The design of bench heights and bench widths, taking into account excavation method and equipment.

> How to orient the quarry faces to stability for blasting and excavation, including consideration of failure modes and how they will be managed.

> An assessment of the suitability of the design for short and long-term stability and maintenance of the faces.

> An indication of the probability of failure or the factor of safety of the overall excavation.

> The inspection and monitoring requirements.

> The design must also allow adequate space for haul roads with provision for safety features as necessary, ie
  - suitable road widths, with
  - inner rock trap and berm,
  - outer edge protection (ie windrow) and
  - face edge stand-off.

3.5 SLOPE DESIGN

At mines or quarries there is a tendency to increase the slope angle to decrease waste rock stripping and possibly generate higher return on investment. However, increasing the slope angle decreases the stability of the slope. This could lead to safety implications and higher operating costs due to slope failures.

By applying sound geotechnical engineering practices, safe slopes can be designed and maintained in almost any geological environment.

Varying parameters of bench height, bench width, batter face angle, and inter-ramp slope height and slope angle all contribute to improve overall slope stability. Examples of each are provided below.

3.5.1 SLOPE STABILITY ANALYSIS AND FACTOR OF SAFETY (FOS)

Fundamental to slope stability analysis are the anticipated modes of failure, the scale of the slope, available data and the perceived risk relevant to the particular stage of the slope.

Whether a particular failure is ‘acceptable’ will depend on its consequence and risk. If the failure of a particular slope has no bearing on its surroundings or safety and production, it is likely to be of minimal concern. However, this is generally not the case. As such, slopes need to be designed to an acceptable standard taking into account the consequence of failure and the inherent uncertainty in the geotechnical model.

Slope design is essentially governed by two factors, the consequence of failure and the degree of inherent uncertainty. It is usual practice to apply a FOS or POF to the design geometry. When the consequence of failure or the level of uncertainty is high, the design criteria should be altered accordingly (resulting in a more conservative design). An example of the FOS and POF design criteria approach is shown in Table 3.
### TYPES OF ANALYSIS

When developing stability analysis criteria it is critical to have an understanding of the origins and limitations of the various geotechnical engineering design procedures when applying them. Further information on the following types of analysis can be found in Appendix E: Types of Analysis:

- rock mass rating (RMR) and mining rock mass rating (MRMR) Classification Systems
- kinematic analysis of structurally controlled failures
- limit equilibrium analysis
- numerical analysis.

### MODES OF FAILURE

Collecting and interpreting information on major structures and other geological features is important in determining failure potential.

Steeper and higher slopes or batters will generate greater driving forces. This increases the potential for rock mass failure, presenting a higher risk. Slopes or batters excavated within rock masses that contain persistent geological structures have greater potential to develop large wall-scale failures.

Control of large failures is generally more difficult and important than small failures.

This section contains information on dams as well as the tips, ponds and voids principal hazard. This is because dams are often covered by this PHMP, particularly with tailings dams. Potential large scale failures are usually controlled by:

- excavating slopes or batters to a shallower angle
- depressurisation of groundwater in the rock mass
- installing ground support and reinforcement.

Using ground support and reinforcement to control large scale failures is generally more costly than when used for discontinuities with shorter trace lengths.

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* Where a mutually acceptable agreement to allow excavation cannot be made between the quarry or mine owner and the “owner” of the adjoining structure or plot of land. Note a higher standard of geotechnical data is required for the design of category 3 slopes compared to category 1 and 2 slopes.
Basic modes of failure are listed below (Girard J.M. 2012).

**Step-path failure** is similar to planar failure, but the sliding is due to the combined mechanisms of multiple discontinuities or the tensile failure of the intact rock connecting members of the master joint set.

**Planar failures** occur when a geological discontinuity, such as a bedding plane, strikes parallel to the slope face and dips into the excavation at an angle steeper than the angle of friction.

**Wedge failures** occur when two discontinuities intersect and their line of intersection daylightst in the face.

**Ravelling:** Weathering of material and expansion and contraction associated with freeze-thaw cycles are the main causes of ravelling. This type of failure generally produces small rock falls, not massive failures.

**Toppling** can occur when vertical or near-vertical structures dip toward the pit. In this case, the bench face height should be limited to a distance roughly equal to the bench width. This will help catch any toppling material and decreases the chances of impacting work on the pit floor.
Circular failures (or slumps) generally occur in weak rock or soil slopes. They do not necessarily occur along a purely circular arc, but some form of curved failure surface is normally apparent. Failures can occur at the surface (slope failure), at the toe (toe failure), or at depth in a weak zone.

**3.5.2 BATTER AND FINAL BENCH DESIGN**

Slopes are generally designed as a series of batters separated by benches, at predefined height intervals.

Benches should be wide enough to stop potentially hazardous rock falls and contain any spills from the batters above.

The final decision on the maximum batter height should be based on:

> reliability of the batter slope (i.e. stability under potential failure modes)
> availability of equipment for adequate scaling to remove loose pieces of rock.

For reliability of the batter design, all possible failure modes should be identified and their stability assessed by kinematic and limit equilibrium analyses, as appropriate.

Further information about batter and bench design can be found in Appendix F: Batters and final bench design, including information on:

> batter height and reach
> final bench spacing
> final bench widths.

**3.5.3 OVERALL SLOPE DESIGN**

The methods of analysis required for overall slope design are the same as those used for the batter design, except the scale is different. In stronger rocks, overall slopes may fail by planar and wedge sliding. In soils and weak rocks, they may fail by toppling and rotational shearing. More complex collapses involving failure through the rock mass will require analysis by numerical methods.

Batter stability immediately below and above the access ramp should also be considered when designing inter-ramp slopes. Batter instability immediately below could undermine the ramp and instability immediately above could spill onto the ramp.

**3.5.4 WORKING BENCH WIDTHS**

To determine working bench widths, consider the type of equipment and the method of mining or quarrying. You should ensure there is enough room to allow the:

> cordonning off of unsafe ground conditions that may occur
> roadway to be located away from the face
> excavating mobile plant to work
> correct positioning of trucks being loaded
> safe queuing of trucks while waiting to be loaded.

People should not be allowed to work near or under hazardous faces or banks. Unsafe ground conditions should be corrected promptly, or the area cordoned off.

**3.5.5 GROUNDWATER AND SURFACE WATER CONTROL**

Mines or quarries excavated below the ground water table may need some form of dewatering and depressurisation. The most significant related problem is the effect that water pressure has on the stability of the slopes. Water pressure in structural defects in the rock mass, and pore spaces
in rock material reduces effective stress, and consequently shear strength.

At some sites, with minor ground water inflow from slopes or floor, evaporation alone can account for all dewatering requirements. At other sites, major pumping operations may be necessary. The approach to ground water control can be by means of water abstraction methods such as:

- using production bores
- through sumps or trenches
- through sub-horizontal drainage holes drilled into the slopes.

Each method can be used individually or in combination to produce the required result. Selection of the most appropriate method will depend largely on the local and regional hydrogeological conditions, the relative importance of depressurisation to the specified design and the required rate of production. At large extractive sites, all three methods may be required for groundwater control. The production bores can be used in advance of and during extraction.

Control of surface drainage is also an important aspect of the implementation of the slope design. Surface water drainage paths through and around the site should be designed, constructed and maintained so that water does not pond at the crest or toe of critical slopes. To stop scouring on a face, water should not be discharged over a face except in a single controlled point. If possible, the water should be directed along the bench to the roadway, and along an open drain to a collection point, sump or settling pond.

### 3.6 GROUND SUPPORT AND REINFORCEMENT SYSTEMS

A number of factors influence whether ground support is required. The basic principle of ground support and reinforcement is to allow the operator to maintain the same overall slope angle while retaining the overall factor of safety. This is important when addressing zones of weakness to maintain a consistent design shape. Safety is paramount, but economic viability and the various requirements based on operating type also influences design decisions.

Ground support and reinforcement systems (artificial support) may include retaining walls, placement of rock or cable bolts. It also may include structures such as drilled or cast in-place piles, earth and rock anchors, reinforced earth including the use of geotextile and protection against erosion.

#### 3.6.1 DESIGN CONSIDERATIONS

When providing artificial support you should match the design of the support system to the ground conditions. Design methods for artificial support should consider:

- the function of the support (e.g., to prevent rock fall, slope failure or rock slide)
- geological structure in and around the slope
- in situ rock mass strength and behaviour of the rock support or reinforcement system under load
- groundwater regime and chemistry, rock stress levels and the changes in rock stress during the life of the excavation
- the potential for seismic events (earthquake or blasting)
- retaining the overall factor of safety.

**Effect of timing of installation:** Generally, the earlier artificial support is installed the more effective it is. In areas requiring support, installation should be undertaken as soon as practicable to limit potential loosening and unravelling of the rock mass. Extended delays in the installation may jeopardise effectiveness of the artificial support. Ideally, identified wedges or blocks that are potentially unstable should be secured as excavation continues, with artificial support being installed progressively.

**Corrosion:** The influence of corrosion means no conventional forms of artificial support will last indefinitely - they all have a finite design life. The use of galvanised components is one way in which the life of the support will be prolonged.
Quality control: Each element or layer of artificial support should be combined so that the overall system is well-matched to the ground conditions for the design life of the excavation.

You should develop a quality control procedure to ensure the standard of installation of artificial support meets the design expectations for all ground conditions at the site.

3.6.2 ARTIFICIAL SUPPORT MEASURES

Artificial support measures can be categorised into four main groups (Read and Stacey 2009):

- rock bolting systems
- retaining type structures
- surface treatments
- buttressing.

ROCK BOLTING SYSTEMS

Rock bolting systems typically fall into three categories: rock bolts, dowels (shear pins) and cable bolts. Rock bolting systems can be improved by connecting individual components by welded mesh or strapping.

More information on rock bolting systems can be found in Appendix G: Rock Bolting Systems.

RETAINING TYPE STRUCTURES

Retaining walls are typically formed from precast concrete or in situ poured concrete, steel sheet piling or bored piles. Walls can be reinforced or un-reinforced and can be tied back with tendons into the rock.

Proper drainage behind the wall is critical to their performance. Drainage material will reduce or eliminate the hydraulic pressure and increase the stability of the fill material behind the wall.

More information on retaining type structures can be found in Appendix H: Retaining type structures.

SURFACE TREATMENTS

Shotcrete lining provides ground support and can lock key blocks into place. It also protects the rock against erosion by water and weathering. To protect water-sensitive ground, the shotcrete should be continuous and crack-free and reinforced with a wire mesh or fibres.

Fibrecrete (steel fibre reinforced shotcrete) was introduced in the 1970s and has gained worldwide acceptance as a replacement for traditional wire mesh reinforced plain shotcrete. Steel fibres are incorporated in the shotcrete to improve its crack resistance, ductility, energy absorption and impact resistance characteristics. Properly designed, fibrecrete can reduce or eliminate cracking, a common problem in plain shotcrete.

Slope erosion protective measures – slopes which are highly susceptible to erosion should be protected from rain and wind. A rock or cobble cover of 300 mm thickness is usually sufficient to protect against wind and rain. Alternatively grasses can be used.

Rock netting - linked steel wire and rings connected into sheets. Draped over a face, they limit rock movement and the energy in any movement. Useful in poor ground where fretting needs to be controlled.

Hydro-seeding – is a popular method of quickly establishing grasses on steep batters.

BUTTRESSING

A simple method of increasing slope stability is to increase the weight of material at the toe, creating a counterforce that resists failure. A berm or buttress of earth or rock fall can simply be dumped onto the toe of the slope.

Brocken rock or riprap is preferred to overburden because it has a greater frictional resistance to shear and is free draining, reducing problems with plugging groundwater flow.

Shear trenches or shear keys provide increased shearing resistance to failure and also serve as a subsurface drain. A shear trench is frequently a good supplement to flattened slopes and berms. Shear trenches should extend the full length of the slope.
PART B

04/

PLANNING FOR TIPS, PONDS, VOIDS AND DAMS

IN THIS SECTION:

4.1 Appraisal of tips, ponds and voids principal hazard
4.2 Tips, ponds or voids principal hazard management plan (PHMP)
4.3 Planning and design criteria for tips
4.4 Planning and design criteria for ponds or dams
4.5 Construction of a tip or pond
4.6 Rehabilitation of tips
A well designed and constructed tip, pond or dam will have the lowest long-term and operational risk (eg structural failure).

This section describes:
> how to identify and manage hazards from tips, ponds, voids, and dams
> the role of geotechnical assessments
> criteria for planning and designing tips, ponds, and dams
> processes for constructing and maintaining safe tips, ponds, and dams.

The design of tips, ponds or dams should allow for:
> slope of the foundation
> geotechnical properties of the base and material
> earthquake risk
> surrounding area drainage, surface drainage and under-drainage
> size and lifespan
> adjacent infrastructure and land ownership
> final landscape and stability requirements
> equipment and operational methods to be used.

4.1 APPRAISAL OF TIPS, PONDS AND VOIDS PRINCIPAL HAZARD

The SSE must carry out an appraisal of the mining operation to identify principal hazards at the mining operation\(^6\).

To determine if tips, ponds or voids are a principal hazard, you should consider how a tip, pond or void might feasibly fail, and the likely consequences of any such failure. The probability of such a failure actually happening is not relevant in this context.

The consequences depend on:
> the likely scale of the failure (ie the size of the failure and the area affected by it)
> whether people are likely to be fatally injured.

Use a competent person for technical input and advice during the appraisal process, as required.

As a guide, complete an appraisal to determine whether a tips, ponds or voids principal hazard exists where:
> The tip is, or will be, in a wholly or mainly solid state and not in solution or suspension (ie not likely to flow if not contained) and
  - the area of the tip exceeds 10,000 m\(^2\) or
  - the height of the tip exceeds 15 m or
  - the average gradient of the land covered by the tip exceeds 1 in 12.

Or
> The tip or pond contains, or will contain, any liquid or material wholly or mainly in solution or suspension (ie likely to flow if not contained) and
  - the contents of the tip or pond is more than 4 m above the level of any land which is within 50 m of its perimeter or
  - the contents of the pond exceeds 20,000 m\(^3\).

Or
> Irrespective of the size of the tip, pond or void, other factors (eg the geology, location or proximity to an excavation) means there is a principal hazard.

Or
> Vehicles operate near the edge of a tip, pond or void.

\(^6\) The Regulations, regulation 66 (1) (a)
Area covered by tip or stockpile >10,000 m²

Figure 12: Guidance for tips (solid)

Content of tip >20000 m³ (excluding containment bund)

50 m

Height >4 m

Figure 13: Guidance for tips (liquid) and ponds

A risk assessment must be completed for the tips, ponds, and voids principal hazard. A description of how the risk assessment will be conducted and the results of the risk assessment must be included in the tips, ponds, and voids PHMP7.

In addition to the above, the SSE must ensure a risk reassessment of the stability of the tip, pond, or void is carried out by a competent person at least once every 2 years after the date the SSE has approved the PHMP, and, where construction of a tip, pond or void deviates from the geotechnical design, and, if a new tip, pond or void is created8.

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7 The Regulations, regulations 68 (b) and (c)
8 The Regulations, regulation 82
4.2 TIPS, PONDS AND VOIDS
PRINCIPAL HAZARD MANAGEMENT PLAN (PHMP)

Where an appraisal has recognised a principal hazard, the SSE must ensure there is a principal hazard management plan (PHMP) for it.9

Regardless of the result of the risk appraisal, a mining operation must have a PHMP if a tip is or will be:
> located on a slope
> greater than 15 metres high
> greater than 100,000 m³ in volume.10

The tips, ponds or voids PHMP must contain information detailed in regulations 68 and 81 of the Regulations. In summary, regulation 81 requires information on:
> procedures and processes for the safe design, construction and maintenance of tips, ponds or voids
> a geotechnical assessment
> road design and traffic movement
> the dumping rules
> records of material tipped
> an inspection and monitoring regime.

Where regular inspections are required by the PHMP, the PHMP must specify the nature and interval of inspections. It must also specify the appointment of a competent person to supervise the conduct of dumping operations, including a requirement this person supervises every inspection of a tip on the site.11

The tips, ponds and voids PHMP should be developed in the context of the whole health and safety management system, not in isolation. This will ensure gaps and overlaps are identified and used in the implementing of suitable controls for tips, ponds, and voids.

For more detailed information on the content of the PHMP, and its relationship with other management and controls plans, processes and procedures see WorkSafe’s Guidance for a hazard management system for mines.

4.2.1 GEOTECHNICAL ASSESSMENT

Where a tip, pond or void has been appraised as a principal hazard, the PHMP must include a geotechnical assessment. This must be proportionate with the type and scale of tipping operations and consider:
> the underlying geotechnical structure at the tip site
> the properties of the material being tipped
> the creation of any ponds or voids.12

A geotechnical assessment will dictate any foundation and surface treatment required and may include any or all of:
> removal of unsuitable, weak material in the foundation
> benching of the foundation
> installation of under-drains and final slope toe drains
> installation of surface cut-off drains.

Using data collected from the geotechnical assessment, develop a geotechnical design which establishes appropriate foundations. A geotechnical recommendation for the maximum lift height, depths, volumes and maximum overall tip height should be provided as part of the geotechnical design.

4.2.2 RECORDS TO BE KEPT

Where a tip or pond has been appraised as a principal hazard, the PHMP must provide for record keeping of the materials being tipped.13

Quarry and alluvial mines are recommended to keep records where the tip or pond has been appraised as a principal hazard.

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9 The Regulations, regulation 66 (1) (b)
10 The Regulations, regulation 66 (c)
11 The Regulations, regulation 83
12 The Regulations, regulation 81 (b)
13 The Regulations, regulation 81 (e)
4.3 PLANNING AND DESIGN CRITERIA FOR TIPS

You should proactively design and plan dumping activities - not rely solely on “reactor design”. You should be aware of the properties of the overburden, and the influence of the local environment on tip stability.

To make sure health and safety hazards are controlled, consider:

> the geological nature of the area (in particular the foundation of the tip)
> the quantity, type, and rehabilitation of overburden
> the type and size of the mobile plant to be used and access roads for vehicles and pedestrians
> preparation of the receiving area
> settling requirements, drainage and runoff controls
> stabilising methods, including inspections
> spontaneous combustion susceptibility
> controlling public access
> any other hazards which may affect safety (eg overhead power lines).

Tips should be designed to take into account the full range of foundation materials, tip materials and ground and surface water conditions.

Prepare all tip sites to safely receive the material. This includes removal of vegetation and topsoil, and keying into the substrata to ensure the stability of the material placed above.

Where tree felling is required, competent workers with appropriate tree felling qualifications must be used to undertake the work. You must notify WorkSafe in writing at least 24 hours before you intend to undertake tree-felling.

Subsoil drainage should be considered, to ensure there can be no liquefaction of the material placed there. Subsoil drainage can be as simple as placing large rocks to allow moisture to “wick” through. However, this could be a more sophisticated system using drain coil and piping to capture and transport moisture through the material, to a controlled discharge below the tip. Design water diversion and drainage structures according to acceptable engineering standards and perform to these for the full life of the tip.

Where rehabilitation is required, undertake this as soon as possible to prevent scouring and water damage through erosion.

Design access roads and other vehicle operating areas to acceptable engineering standards for the number and type of vehicles requiring access. Design criteria should include road width, road gradient, edge protection, signage, speed limits, lighting, overhead hazards and passing rules. Refer to section 5 for further information on roads.

Adjacent stockpiles can have an effect on each other; for example, stability may be altered where they overlap. The adequacy of vehicle routes should also be considered when planning the position and size of stockpiles. In particular, the risk of collision can be minimised by ensuring a clear field of view for drivers (refer section 11.9.4).

As part of planning you should include appropriate edge protection (refer sections 5.3.9 and 8.2.3).

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14 Health and Safety in Employment Regulations 1995, regulation 26
4.4 Planning and Design Criteria for Ponds or Dams

The site for a pond (or tailings dam) must be selected to eliminate hazards or minimise the potential impact on people. This includes during operations, decommissioning and after abandonment, particularly in the event of the following:

- seepage
- dust generation
- exposure to chemicals or hazardous particulates
- erosion
- overtopping
- abrupt failure of retaining structure
- impediment of surface water flows
- pollution.

Physical factors that should be considered during site selection and design include:

- hydrology (potential for flooding and catchment area characteristics)
- topography (influence of watershed, streams, and creek systems)
- foundation material (water tightness, strength, and liquefaction potential)
- foundation conditions (physical, geochemical, and geotechnical properties)
- characteristics of construction (suitability, availability, and proximity)
- characteristics of tailings material (physical, geochemical and geotechnical properties)
- climate (rainfall patterns, evaporation rates and prevailing winds)
- geology (faults, fractures, shear zones and areas of instability)
- hydrogeology (potential impact on ground water resources)
- seismicity
- minimum freeboard
- seepage control methods

- characteristics of embankment or other retaining structures (stability, erosion resistance, resistance to dynamic or static liquefaction and integrated waste landform)
- operating strategy
- requirement for access
- characteristics and availability of cover and rehabilitation methods
- whether there are any populated areas downstream which may be adversely affected in the event of a failure.

Site abandonment should be considered during the design stage to ensure post-abandonment performance will meet stakeholder expectations and regulatory requirements. Abandonment and rehabilitation planning should ensure the pond disposal area is left such that it is able to:

- maintain an acceptable level of hazard controls (eg for dust control, access, and so on)
- remain structurally stable
- resist deterioration through erosion and decay
- prevent loss of containment.

4.5 Construction of a Tip or Pond

You should develop and implement a construction plan to ensure the tip or pond construction meets design specifications and tolerances. This should include quality assurance procedures. The plan should also contain systems of work and procedures to ensure the proposed construction can be carried out safely.

Use a competent person to ensure construction of tips or ponds meet design specifications and tolerances, and that the following are documented:
the conditions encountered during construction (including field and laboratory testing). This should be verified against those assumed in the design.

> corrective measures taken where conditions did not meet the original design or specifications.

> all changes required that deviated from the original design.

> the testing and measurement regime to validate the design parameters.

> survey data and drawings of the tip or pond construction.

The true locations of the following features should be shown in your design:

> borrow pits and embankments.

> drains and seeping trenches.

> topsoil stockpiles and capping material sources.

> process water and return water ponds.

> monitoring instrumentation.

> decant towers.

> buried pipework and cables.

The construction records and monitoring data form the basis of the design of subsequent stages. Where construction is staged, a separate construction report should be prepared for each stage.

Your tip or pond may also be considered a dam under the Building Act 2004. You can view the Building Act 2004 at www.legislation.govt.nz.

4.5.1 DRAINAGE OF A TIP

If sufficient water is present, either from heavy rainfall or other sources, some or all of a tip can become saturated. In this case the water in the saturated portion has a buoyant effect and reduces the strength of the material, making the tip more prone to sliding. As such, measures should be taken to ensure water drains away. Water should never be allowed to accumulate against or on any part of the tip, unless it is specifically designed as a dam or pond.

Where tips are constructed above an existing water course, the water course should be diverted or culverts of sufficient size provided to channel the water through the tip area.

The tip should have internal drainage to deal with expected rainfall. This is usually provided by under-tip drains or coarse, permeable layers positioned at appropriate levels. Internal drainage systems should be designed by a suitably competent engineer or hydrologist.

Drainage systems must be maintained.

4.5.2 DAM SAFETY SCHEME

For storing water or another fluid under constant pressure you must comply with the requirements of a dam, as set out in the Building Act 2004. Structures at extractives sites that may fit the definition of a dam include settling ponds, tailing dams and reservoirs.

For more detailed information on dam notifications, dam classification, dam safety assurance programmes or dam compliance certificates see www.dbh.govt.nz.

4.5.3 SMALL DAMS

Dams are to be designed, built and maintained to an appropriate standard. Substandard dams can fail, causing injury to workers, as well as, damage to equipment and financial loss.

The following information was supplied by the Ministry of Business, Innovation and Employment. The information does not prescribe how small dams should be constructed or maintained. It is a guide on ensuring a dam complies with statutory requirements, including those in the Building Act 2004.
For further general information on inspecting small dams, constructing small dams or the Building Code see the following documents available at www.dbh.govt.nz/small-dams-guidance:

> **The New Zealand Society of Large Dams (NZSOLD)** – Guidelines on inspecting small dams.
> **The Auckland Regional Council** – Dam Safety Guidelines.
> **The Building Regulations 1992 (Building Code).**

As provided by guidance issued by MBIE, a small dam can be considered any dam that:

(a) has a height of less than 4 metres; or
(b) holds less than 20,000 cubic metres volume.

However, the Act states that all building work carried out must comply with the Building Regulations 1992 (also known as the Building Code). Building work includes the construction and alteration of small dams even though they are exempt from requiring a building consent for this work.

The Building Code sets out performance standards that building work must meet, and covers aspects such as structural stability and durability. The Building Code does not prescribe how building work should be done (it has no detailed requirements for design and construction), but states how completed building work, and its components, must perform. This is important when considering the construction of a small dam, as each dam is unique to its location and environment.

Design, construct and maintain all dams in a way that:

> safeguards people and property from structural failure
> complies with the Building Code throughout its life
> has a low failure probability.

**CONSTRUCTION OF A SMALL DAM**

The construction of a small dam, although not requiring building consent, requires careful consideration of design and construction methodology. In the first instance, you should employ a technical expert to provide advice on designing and constructing a small dam to make sure it is fit for purpose and it complies with the Building Code.

A small dam is expected to have the following features:

**Foundations and structural support**

The areas of ground on which the dam is located (including the areas of adjacent ground) form part of the total water barrier. If the foundations do not adequately support the basic small dam structure, or are weak or prone to high seepage flows, they can cause the dam to become useless or to fail. The foundation of a small dam is often the natural materials on which it stands. A clean, stable foundation of adequate strength and low permeability is vital for a small dam’s durability and performance. An adequate seal at the dam foundation and abutments must be formed to reduce leakage from the reservoir. Otherwise, it may not fill or excessive seepage may cause dam failure.

**Spillway and high stream flow prevention**

All dams require at least one working spillway. A flood spillway prevents high stream flows caused by heavy or prolonged downpours from overtopping the dam crest. This causes erosion of the dam materials, and may lead to a breach of the dam. The flood spillway is normally formed around the end of the small dam and extends downstream, clear of the dam toe. The flood spillway must be of a size adequate for flood flows expected for the rainfall and catchment size or topography. A smaller service spillway for a small dam may also exist and will normally be a culvert or pipe which takes normal flows.
**Storage capacity**
Assess the volume of storage to ensure it is large enough for the intended purpose. Sufficient freeboard must be provided to prevent overtopping of the dam.

**Embankment and slope angles**
The embankment must have a crest of sufficient width, and may require protection if vehicles or heavy stock will have access. The upstream and downstream slope angles need to be chosen carefully, to ensure the embankment slopes are stable. To ensure a high standard of compaction, the fill material needs to be carefully selected, sufficiently impervious, and placed at the correct moisture level and thickness of each layer. Riprap may be required on the upstream face to protect the dam against wave lap erosion.

**Pipes and conduits**
Pipes are often placed through the bottom of the dam for drawing of water. However, it is important to note these can also be weak points for seepage, causing erosion of the dam fill. Technical advice is recommended for correct design details where pipes pass through a dam.

### 4.6 Rehabilitation of Tips
When the site is temporarily (suspended) or permanently closed (abandoned), it should be left in a safe condition.

Typically rehabilitation is carried out progressively, meaning parts of the site can be abandoned, while other parts are still operational; for example, rehabilitation of overburden tips that have reached capacity.

The objectives of abandonment of all or part of a site are:
> to make sure the site is self-sustaining and prevent or minimise environmental impacts
> to rehabilitate disturbed areas for a land use (e.g., return of disturbed areas to a natural state or other acceptable land use).

Rehabilitation should address management of water runoff, air quality, stability of material, erosion control, and treatment and containment of any possible hazardous substances.

Stability of material and control of water runoff are the most important as they will be the first indicators of any problems in the rehabilitated area. Stability should be monitored by study of the toe area of any overburden tip. Ensure it is well compacted and not bulging or moving out from its original placement. Another indicator of movement would be cracks appearing around the crest or top of the rehabilitated tip.

Rehabilitation is a requirement for all new resource consents and most current resource consents.

Rehabilitation should be considered and incorporated into all aspects of site planning, construction and operation. This allows key aspects of the abandonment to be planned for throughout the site’s life cycle. Plans should identify measures to be undertaken during the operations phase that are aimed at progressive rehabilitation of disturbed or developed areas of the site.

Review and revise rehabilitation plans as necessary throughout the site’s life cycle. The plans may become more detailed, incorporating more activities related to the site and consideration of more site conditions and monitoring results.
IN THIS SECTION:

5.1 Appraisal of roads and other vehicle operating areas

5.2 Roads and other vehicle operating areas principal hazard management plan

5.3 Design and layout of roads
Roads and other vehicle operating areas can introduce significant hazards at an extractives site. However, a well-designed and maintained site will make workplace vehicle accidents less likely.

This section describes how to:

> identify and manage hazards from roads and other vehicle operating areas
> plan and design safe vehicle routes, road structures, gradients, corners, drainage, surfacing, visibility, and areas for working, turning, and stopping
> manage traffic and provide clear information and guidance for drivers.

The overall message is safety by design.

Considering what vehicle activities will be conducted on a road or other vehicle operating areas will help determine the kind of hazards that may be present. The unwanted events associated with roads and other vehicle operating areas include:

> vehicles rolling over or going over edges
> ground failure on to or below vehicles
> collisions between vehicles and unwanted interaction between vehicles and people
> uncontrolled movement of vehicles
> vehicles contacting overhead power lines or other structures.

Assessing the risks will help you take the correct action to eliminate, isolate or minimise hazards.

### 5.1 APPRAISAL OF ROADS AND OTHER VEHICLE OPERATING AREAS

The SSE must carry out an appraisal of the mining operation to identify principal hazards at the mining operation\(^20\).

To determine if roads and other vehicle operating areas are a principal hazard, consider the following factors. The probability of such a failure actually happening is not relevant in this context.

> How a road or other vehicle operating area might feasibly fail and the likely consequences of a failure (eg collapse, slips).
> The type of vehicles using the road or other vehicle operating area.
> The activities that are undertaken and the consequence of any interactions between vehicles and pedestrians, structures or other vehicles. For example vehicles carrying passengers, light and heavy vehicle interactions, travelling under overhead power lines, loading over a cab where a driver may be present and so on.
> How a vehicle may lose control and the likely consequences (eg driver falling asleep, mechanical failure, tip over).
> The hazards on the road or other vehicle operating area (eg sharp corners, steep gradients, large drop-offs and so on).
> Any other hazard involving vehicles.

Use competent people for technical input and advice during the appraisal process as required.

A risk assessment must be completed for the roads and other vehicle operating areas principal hazard. A description of how the risk assessment will be conducted and the results must be included in the Roads and Other Vehicle Operating Areas PHMP\(^21\).

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\(^{20}\) The Regulations, regulation 66 (1) (a)
\(^{21}\) The Regulations, regulations 68 (b) and (c)
Regularly renew whether intersections and roads are necessary.

**5.2 ROADS AND OTHER VEHICLE OPERATING AREAS PRINCIPAL HAZARD MANAGEMENT PLAN**

Where an appraisal has recognised a principal hazard, the SSE must ensure there is a PHMP.

The roads and other vehicle operating areas PHMP must contain information detailed in regulations 68 and 80 of the Regulations.

Regulation 80 requires the PHMP to provide for the following areas including:

General road design:
- controls for the safe design, layout, operation, construction and maintenance of roads and other vehicle operating areas
- road maximum grade, minimum widths and radius for curves, camber, surface material specifications and drainage needs.

Measures to control risks associated with:
- any banks, steep drops or any other hazard adjacent to the road or other vehicle operating area
- interactions between vehicles, considering speed, volume and other relevant matters
- interaction between site vehicles and public vehicles
- interactions between vehicles and pedestrians
- interaction between vehicles and fixed structures (eg gas pipes and processing machinery) including overhead and underground power lines
- the use of remote control vehicles
- adverse climatic conditions (eg rain, ice, fog).

In relation to dump trucks:
- the design, construction, and maintenance of safety benches, windrows and collision bunds
- measures to manage the risks of trucks overturning
- safe tip areas and routes
- recommended methods of safe working.

Procedures for the operation and movement of loads:
- shifting equipment and discharging loads
- the maximum loads that can be carried or towed.

Worker safety:
- how workers will safely access and exit their place of work
- how workers will safely work or travel on or near roads or other vehicle operating areas
- areas to be considered prohibited zones.

Vehicle safety and maintenance:
- park-up, refuelling and recharging safety requirements
- the safe storage of fuel
- the periodic inspection and testing of the braking system
- the safe operation and requirements of vehicles carrying passengers or transporting equipment including separation of loads, the use of seat belts or other restraint devices and the provision of seating
- how defects identified when inspecting vehicles will be addressed.

The roads and other vehicle operating areas PHMP should be developed in the context of the whole health and safety management system, and not in isolation. This will ensure gaps and overlaps are identified and used in the implementing of suitable controls roads and other vehicle operating areas.

For roads and other vehicle operating areas recognised as a principal hazard, it is likely a mechanical engineering PCP will also be required.

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22 The Regulations, regulation 66 (1) (b)
For more detailed information on the content of the PHMP, and its relationship with other management and controls plans, processes and procedures see WorkSafe’s Guidance for a Hazard Management System for Mines.

5.3 DESIGN AND LAYOUT OF ROADS

Every site is different and likely to present different hazards and risks. However, a well-designed and maintained site with suitable separation of vehicles and people will make vehicle accidents less likely.

Safe workplaces are achieved by separating pedestrians and vehicles, light and heavy vehicles, and providing hazard-free vehicle routes.

5.3.1 TERRAIN AND GEOTECHNICAL CONSIDERATIONS

Take into account the terrain and geotechnical issues when designing and establishing roads. They will impact on the type of operation that will be carried out, the mobile equipment to be used, and where infrastructure can be located.

5.3.2 OPERATIONAL PARAMETERS

Consider how operating parameters will impact on the design, layout, and materials used to construct the road and maintenance requirements prior to constructing and establishing roads. This includes:

> the nature, type and, load of vehicles to use the road
> expected volume of traffic
> operating hours
> vehicle operating speeds
> gradients (including superelevation)
> materials available for road construction and maintenance.

5.3.3 VEHICLE ROUTES

Where practicable you must eliminate the hazard of pedestrians and vehicles interacting. The most effective way of achieving this is to provide separate pedestrian and vehicle routes, and where practicable, separating light and heavy vehicles.

Design roads that are:

> adequate for the number, type and size of the largest vehicles that may use them
> suitable for the varying driver positions which includes height and cab position (eg right, left or centre drivers position).

Roads should:

> have firm surfaces, adequate drainage and safe profiles to allow safe vehicle movements
> be clearly signed
> where appropriate, have edge protection and road markings (eg sealed roads) or delineators showing the right of way
> have speed limits and speed control measures specific to site conditions and the types of vehicles using the route
> have adequate rock fall protection measures (eg a catch ditch, catch bench or suitable barrier)
> be clearly delineated in the hours of darkness by using reflective marker pegs or similar devices or have suitable access restrictions to hazards (eg ponds or other water filled hazards or steep drop-offs)
> allow for break back of the bench crest during the life of the road. The amount of break back will depend on geotechnical characteristics of the bench
> minimise the need for reversing with one-way systems and turning points
> accommodate the turning circles of vehicles.
Also consider:
> access to the site including weight restrictions on bridges, narrow roads and so on
> where distribution points will be (e.g., processing areas, weighbridge location, load covering areas, loading areas, points of sale to the public)
> impacts of land adjacent to the road.

Where practicable, road design should avoid:
> unstable areas
> hazards such as excavations, ponds, structures, fuel or chemical storage areas, underground workings or voids and overhead power lines
> steep gradients and tight bends
> one-lane two-way routes.

You may need to engage a specialist traffic engineer for complex traffic flows, especially at sites with large processing operations.

### 5.3.4 ROAD WIDTHS

The width of a road should be based on the size of the largest vehicle in use. The larger the vehicle, the more clearance is required.

Each lane of travel should be at least 1.5 times the width of the widest vehicle that would normally use the road. For a two-lane road, the width should be at least 3 times the width of the largest vehicle. Provide extra room for drains, windrows or centre windrows (refer Figure 14).

![Figure 14: Example road layout with clearance between lanes](image)

Where it is not practicable to have two lane roads, adequate passing bays and turning points should be provided. One-lane roads and turning points are not recommended on haul roads.

It may be appropriate to use turning bays to allow vehicles to turn and drive forwards for most of the time. Turning bays would ideally be a roundabout or a ‘banjo’ type. Although, ‘hammerhead’ and ‘stub’ arrangements may be acceptable.
Where reasonably practicable provide segregation of light vehicle on roads also used by off road dump trucks. This is to eliminate interactions between light and heavy vehicles (refer Figure 16).

The hierarchy of controls for controlling light and heavy vehicle interactions is:
1. Separation (different haul road).
2. Segregation (bund separation on same haul road).
3. Administrative controls.

Consider the interactions of light and heavy vehicles when entering and leaving haul roads.

Bends on haul roads should be designed wider than the straight stretch to allow for overhang of vehicles using it. Switchbacks or other areas on haul roads requiring sharp curves should be designed to take into account the minimum turning radius of the haul trucks.
5.3.5 ROAD GRADIENT

Five important aspects of the steepness or grade of a roadway are:

- The grade needs to be compatible with the braking capabilities of the vehicles (with a factor of safety).
- The grade needs to be compatible with the performance capabilities of the vehicles.
- The grade will affect a vehicle's stopping distance.
- The grade selected will have to take into account a vehicle's ability to operate safely in wet conditions.
- Superelevation affects the speed around bends.

DETERMINING THE GRADE OF A ROAD

The steepness of a road is normally expressed as a ratio. The ratio is determined by measuring the distance travelled along the road in relation to the vertical height change (see Figure 17). For example, a road with a 1-metre vertical change over a travelling distance of 10 metres is a 1:10 ratio.

Information in vehicle manuals about braking and performance abilities on slopes may be provided as a grade percentage (see Appendix A for conversion chart).

The steepness of a road should be measured using surveying equipment. The grade should be determined over a portion of the road where the grade is constant. Where the steepness varies, the grades should be determined for different segments.

GRADE AND VEHICLE COMPATIBILITY

The grade of a road must be compatible with road conditions, the type of road surface and the vehicle capability. Vehicle brakes must be able to stop in the worst case scenario without losing control of the vehicle. Particular attention should be paid when loads are moved downhill.

Different vehicles, with different performance characteristics, will use the roads. Design the roads to allow all vehicles to operate within their safety parameters. Road grades should never be designed to the maximum climbing or descending capacity of the vehicles that use them. Generally, a gradient of 1:8 or less should be applied when planning haul road layouts.

It is important vehicles are not overloaded as brake or retarder performances depend on the grade and on the vehicle's total weight (refer 11.4.3).

GRADE SITUATIONS TO AVOID

Avoid road alignments that result in a sharp bend near the top of a grade. These are hard to see at night, when headlights tend to shine up into the darkness. If this cannot be avoided, the bend should be defined, for example, using extended reflective markers.

Also avoid sharp bends near the bottom of a grade. Here, vehicles tend to pick up momentum, making it more difficult to maintain control around the bend. If you cannot avoid a sharp bend, a safe speed for descending the grade should be posted as well as adequate restraining measures, such as large windrows or runaway provisions should be used (refer 5.3.9 and 5.3.10).

SUPERELEVATION

Superelevation is a technique used to assist vehicles in manoeuvring safely around corners. Superelevation is the banking of the road pavement at bends. It allows the vehicle taking
the corner to counteract forces towards the outside of the bend, by directing the vehicles weight towards the centre or radius of the bend. The amount of superelevation on a bend is directly related to the radius of the corner and the desired vehicle speed through the corner.

The following table is a guide for providing the superelevation necessary to reduce lateral forces. The maximum superelevation should be regarded as 1:20.

<table>
<thead>
<tr>
<th>TURN RADIUS (M)</th>
<th>SPEED (KM/HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td>45</td>
<td>1:25</td>
</tr>
<tr>
<td>60</td>
<td>1:37.5</td>
</tr>
<tr>
<td>90</td>
<td>1:50</td>
</tr>
<tr>
<td>150</td>
<td>1:100</td>
</tr>
<tr>
<td>215</td>
<td>1:100</td>
</tr>
<tr>
<td>300</td>
<td>1:100</td>
</tr>
</tbody>
</table>

Table 4: Recommended super-elevation

Superelevation is a particularly important design consideration for switchbacks on haul roads, as they typically have a small turn radius. On switchbacks, which have the centre of the bend located on the up-side of the road, a well-chosen superelevation rate prevents material being spilled from laden trucks and improves vehicle control.

As with changes in grade, transition into and out of superelevated bends needs to be smooth, so vehicles can be eased into corners. Superelevation transition lengths depend on the cross fall change and the design speeds. The larger the change in road alignment, the longer the transition needs to be. Transition lengths should be applied so one-third is on the bend and two-thirds are on the tangent (refer Figure 18). Table 5 outlines the recommended lengths.

<table>
<thead>
<tr>
<th>VEHICLE SPEED (KM/HR)</th>
<th>16</th>
<th>24</th>
<th>32</th>
<th>40</th>
<th>48</th>
<th>56</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross slope change per 100 m pavement</td>
<td>0.08 m</td>
<td>0.08 m</td>
<td>0.08 m</td>
<td>0.07 m</td>
<td>0.06 m</td>
<td>0.05 m</td>
</tr>
</tbody>
</table>

Table 5: Recommended transition lengths
To illustrate the use of this table, assume a vehicle is travelling at 32 km/hr on normal pavement with a cross-fall of 2%. The vehicle is approaching a switchback with superelevation of 4% the opposite way. The total cross slope change here is 6% (2% plus 4%). For a vehicle travelling at 32 km/hr the recommended change is 0.08 m per 100 m. Therefore the total transition length is 75 metres ((6%/0.08 m) x 100 = 75 m).

5.3.6 SIGHT DISTANCE

“Sight distance” is simply how far along the road a driver can see ahead of their vehicle (see Figure 19). Roads should be designed to give drivers a sufficient distance of clear vision ahead so they can avoid unexpected obstacles. A basic rule of safe driving is that, at all times, a driver must be able to stop the vehicle within their sight distance. If a driver sees a problem, such as a boulder on the road or a stalled vehicle, they must be able to stop in time to avoid it.

Design roads with viewing distances and alignments so that a vehicle rounding a bend, cresting a hill, descending a grade, or approaching a junction can stop in time to avoid an object in the road or a vehicle pulling onto the road (refer Figure 20). Consideration should be given to the height of a driver in different vehicles.

SIGHT DISTANCE IN BAD WEATHER OR AFTER DARK

The sight distance can be reduced during inclement weather, such as rain, snow or fog. Under these conditions, drivers must slow down to the point where they can stop within the available sight distance. Effective headlights and spotlights improve the ability to see and be seen.

When driving after dark, sight distance can be defined by the distance illuminated by the vehicle’s headlights. Drivers should reduce their speed so they can bring the vehicle to a stop within the illuminated distance. This distance will vary with the type of headlight. To be most effective, you should keep headlights properly aimed and clean. Speeds should be reduced at night because drivers typically have reduced depth perception, peripheral vision and reaction time.

There is often little contrast in brightness between the background and other objects at an extractive site – especially in snow. Roadside reflectors should be installed to help define the roadway and intersections. Vehicles used at night should have lights that can be seen from the side of the vehicle, as well as the front and rear.
SIGHT DISTANCE AT INTERSECTIONS

Sight distance is important at intersections, where a driver must be able to see oncoming vehicles far enough away to safely turn on to or cross the road. Ideally, drivers should be able to pull on to the road, or cross the road, without requiring approaching vehicles to slow down. The main factors in the safe sight distance at intersections are the acceleration ability of the vehicles pulling on to the road and the speed of the oncoming traffic.

Because of the limited acceleration ability of trucks, especially when laden, ample sight distance should be provided. The higher the speed on the road, the longer the sight distance should be.

Avoid locating intersections near hill crests or sharp curves. In these situations, the sight distance will be limited. Intersections should be kept as flat as possible and sight distance should be considered in all directions.

In laying out intersections, the effect of the large blind spot to the right or left side of haulage trucks (depending on the position of the driver’s seat), should be considered. Intersections where trucks need to stop or give way to other vehicles should be angled to optimise the driver’s ability to see vehicles coming from both the right and left sides (refer Figures 21 and 22). For roads used by haulage trucks, avoid roads that intersect at an angle of less than 90 degrees on the opposite side of the driver. Alternatively compensating measures should be taken (eg convex mirrors, reduced speed zones, communication systems or on-board cameras).

When using ‘Give Way’ controls at an intersection you should have visibility clearance of 1.2 times the priority road speed limit, nine metres back from the intersection. Where you cannot achieve the visibility clearance a ‘Stop’ control should be used that requires vehicles to come to a complete stop (refer examples shown in Figures 23 and 24).

![Figure 21: Intersection with restricted view](image1)

![Figure 22: Intersection with improved visibility](image2)

![Figure 23: Give way control selection](image3)
5.3.7 DRAINAGE

Having good drainage systems will:
> prolong the life of the road
> reduce maintenance costs on roads and vehicles
> minimise downtime
> minimise health effects on drivers
> improve tyre life.

Drainage is normally provided using:

**Cross fall (or cross slope):** Surface drainage is designed to cause the water to leave the road as shallow, non-erosive sheet flow in a way suited to the road material, slope and terrain. To promote drainage either; the road surface should be sloped from one side to the other, or the road should be crowned, or raised, in the centre.

Typical cross falls for unpaved roads in New Zealand are 3.5 to 4% and 2 to 4% for paved roads. On haul roads a cross fall between 2% and 4% is preferred. Steeper crowns can increase tyre wear and metal fatigue in trucks. Cross falls should not be carried around a bend; instead there should be a transition zone between the normal cross fall road and the start of the superelevation of the bend. For more information about superelevation see section 5.3.5.4.

**Free-draining road materials** allow water on the road surface to drain down and out.

**Roadside ditches** collect drainage from the road surface and intercept runoff from adjacent hillsides, keeping it off the road surface.

**Culverts** carry runoff under the road surface to a drainage course. They vary in size from 300 mm concrete or corrugated metal pipes to large shapes 3 m or more in diameter. The inlets and outlets for the larger sections usually have concrete headwalls and wing walls to reduce erosion problems. The smaller pipes usually have bevelled end sections for the same reason.

When using culverts they should be buried deep enough to prevent them being crushed by vehicles passing over them. Manufacturers can provide information about suitable depth.

More information on culverts can be found in Appendix I: Culverts.

5.3.8 ROAD PAVEMENT

Surface and drain all roads adequately to make sure vehicles can be driven safely.

The materials that make up the road pavement and road base need to serve two functions:
> provide adequate traction
> provide support for the vehicles without excessive sinking in or rutting.

**TRACTION**

A road pavement of gravel or crushed stone is preferred for roads. While some other materials provide better traction when dry, a gravel road pavement offers good traction values in both wet and dry conditions. You may have to import gravel or crushed stone when not available on site. Alternatively, if all weather pavements are not practicable and roads become un-trafficable due to weather or under-foot conditions, have procedures in place that outline when operations should stop and when they can re-start. Base any such procedures on technically sound risk assessments.
More information on traction can be found in Appendix J: Traction.

**SUPPORT**

Rutting of a soft pavement can create a hazard by affecting a driver’s ability to control the vehicle and by subjecting the driver to rough or jarring conditions. Rutting occurs when tyres sink into the pavement because the road material doesn’t offer adequate support. Fine-grained soils, even when well-compacted, may not support the tyre loads imposed by large haul trucks, especially during wet conditions.

To prevent or minimise rutting of the road, a road base material with sufficient strength to support the tyre loadings should be provided. A layer of gravel or crushed stone, for example, has higher bearing strength and will distribute the tyre loadings over a larger area. The use of a layer of geotextile can assist in providing a road base that will better support the tyre loadings. A great deal of maintenance work will be necessary to keep the road in good condition where road base material has inadequate support strength.

**5.3.9 ROADSIDE EDGE PROTECTION**

The failure to provide adequate edge protection is the cause of many vehicle accidents. Provide adequate windrows or guardrails where there is a change of level, drop, pond, or other hazards which would put the driver, or others, at risk if the vehicle left the road.

Risk assessments will determine the type of edge protection or runaway provisions require.

**PURPOSE OF WINDROWS**

Roadside windrows are a common safety feature along elevated roadways. However, the capability of windrows may be misunderstood, and it’s dangerous if they give drivers a false sense of security.

Windrows mainly:

- give the driver a visual indication of the location of the roadway edge
- provide a sense of contact to the driver if they accidentally contact the windrow
- provide restraint to the vehicle and give the operator the opportunity to regain control and keep the vehicle from leaving the road
- keep a vehicle back from the edge by a distance equal to at least the width of the windrow.

**EARTHEN WINDROWS**

Windrows used on roads where heavy vehicles operate need to be of sufficient height and width, constructed with suitable material and be steeper on the road side to serve the four functions indicated above.

Windrow suitability is normally judged based on its height, although the effectiveness of a windrow also depends on its width (or thickness) and its firmness.

Earthen windrows should be a minimum of half the wheel height of the largest vehicle that uses the roadway. Windrows less than this or with curved slopes, make an ideal ramp for vehicles to run over and are totally ineffective. Support installation and construction of windrows by robust design calculations determined by a competent person.

*Figure 25: Suitable windrow – firm material big enough to absorb the vehicle’s momentum with a steepened inside slope*
SECTION 5.0 // PLANNING FOR ROADS AND VEHICLE OPERATING AREAS

For more information on windrows, see Appendix K: Windrows.

Windrows can deteriorate due to weathering, and should be regularly inspected and maintained to ensure their continued effectiveness. Mine operators must ensure a competent person inspects windrows at least weekly.\(^\text{23}\)

**BOULDER WINDROWS**

Sometimes a continuous row of boulders is used to form a windrow. When a vehicle contacts a boulder windrow, the restraint comes from the frictional forces involved in sliding the boulder ahead of the vehicle. Boulders cannot be placed right at the edge of the drop off because there has to be a distance available for the vehicle to push the boulders. This distance will depend on the size of the boulders and the size and speed of the vehicle.

For that reason blocks of stone or tyres placed individually along the edge of a road which can be easily pushed out of the way by a vehicle, or increase the risk of injury to the driver, are not suitable for windrows (refer Figure 28). Blocks of stone or tyres may be used provided you heap materials (like scalping’s) between the blocks or tyres so they can safely absorb the impact and not be easily pushed (refer Figure 27).

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\(^{23}\) The Regulations, regulation 222 (1) (a) (ii)
to be higher and stronger than the guardrails typically used on public roads.

Embed guardrail posts deep enough to provide adequate resistance and make the posts and horizontal guide members strong enough to restrain or impede the passage of the vehicle.

Installation and use should not exceed the manufacturers recommended limits in respect to vehicle type, size and weight.

5.3.10 RUNAWAY PROVISIONS

Safety features should be incorporated into road design to guard against the consequences of runaway vehicles. As previously discussed, typical edge-of-road windrows should not be relied on, by themselves, to stop a large haul truck. However, other methods such as the use of escape lanes can bring a runaway vehicle to a safe stop and prevent an accident.

Two types of runaway provision are centre berms and escape lanes.

Centre berms are piles of loose granular material placed strategically along the centreline of the road (refer Figure 29). In the case of brake or retarder failure, the driver manoeuvres the vehicle in line with the berm so the vehicle straddles the berm and is brought to a halt. Consider the following when installing centre berms:

> the nature and size of the equipment that might need to drive on to or straddle the centre bench
> using material to provide sufficient drag on the vehicle
> positioning of the centre berms so vehicles have limited time to pick up momentum
> adequate space between berms to allow the driver time to position the vehicle.

Escape lanes can be used where space is available (refer Figures 30 and 31). Consider the following when installing escape lanes:

> The size and expected speed of a runaway vehicle that might be required to enter the lane.
> Alignment of the lane and the road. An operator of a runaway vehicle should be able to steer the runaway vehicle into the lane.
> Size and length of the lane. The lane needs to be wide enough and of sufficient length to allow vehicle access and time for it to slow and stop.
> Construction material for the lane should offer a high rolling resistance and not tend to compact.
SECTION 5.0 // PLANNING FOR ROADS AND VEHICLE OPERATING AREAS

GROSS VEHICLE WEIGHT

| Less than < 45,000 kilograms | 3.5 m | 1 - 1.2 m | 4.5 - 5 m |
| 45,000 to 91,000 kilograms | 3.5 - 4.5 m | 1.2 - 1.5 m | 5 - 6 m |
| 91,000 to 181,000 kilograms | 4.5 - 5.5 m | 1.5 - 1.8 m | 6 - 7 m |
| More than 181,000 kilograms | 5.5 to 10 m | 1.8 - 3.5 m | 7 - 13 m |

**Figure 29:** Runaway-vehicle centre berm

**Figure 30:** Plan view – haul road escape lane
5.3.11 PARKING AREAS

Consider the following when establishing parking areas:

> separating light and heavy vehicles (including private vehicles – eg workers’ cars)
> locating on as flat, level ground as possible
> being consistent in design and layout
> where possible, have one way systems (limit need for reversing)
> using stop blocks or spoon drains to prevent unintended movement of vehicles
> managing or limiting pedestrian and light vehicle interaction with heavy vehicles
> having clear signage.

For more detailed information on parking areas, see section 11.3.4.

5.3.12 TIPS OR STOCKPILES

When establishing tips or stockpiles think about the vehicle activities that will occur in these areas and set up controls to manage the risks including:

> ensuring there is sufficient room for vehicles to operate
> where possible, have one way systems
> managing stockpiles so they do not encroach on vehicle operating areas
> managing the size of the stockpile so that it does not restrict lateral vision of operators
> restricting light vehicles and pedestrian access
> providing additional lighting if operating at night.

For more detailed information on tips, see sections 4 and 8.

5.3.13 WORKSHOPS AND FIXED PLANT AREAS

A vehicle collision with a pedestrian, machinery or other vehicle is much more likely in workshops and process plant areas due to the restricted vision around fixed plant and doorways. To reduce the risk of this occurring:
provide specific parking areas

restrict vehicle access as much as practicable

establish clearly identified pedestrian crossings and walkways

provide bollards or barriers to protect infrastructure close to roads

establish and sign appropriate speed limits.

5.3.14 SLOPE HAZARDS ABOVE AND BELOW ROADS

Road hazards can be created due to instability of material either above or below the road. The hazard from above is for rock falls or slides of material onto the road which could endanger passing vehicles. The hazard from below is that ground will not be stable or have sufficient strength to support the vehicles using the road, especially when roads are constructed on fill areas. You should establish exclusion zones to avoid these hazards.

Pay special attention to the stability of any area where water is seeping out of a slope - the presence of water tends to make slopes less stable. For more detailed information on drainage and depressurisation see section 3.5.5 and 5.3.7.

For more detailed information on slope hazards, see section 3.

ROCK FALLS

Where roads are adjacent to any highwalls, slopes or tips containing large rocks, you should make sure vehicles are protected from potential rock falls. Rock slopes tend to become less stable over time due to factors such as weathering and the effects of water. They should be regularly checked for overhangs, open joints or other evidence of unstable rock. Unstable material should be either removed, supported, or the area isolated so drivers are not exposed to a potential rock fall (eg catch berms or rock fall fences).

Consider how high and how far out from the wall the structure must be if using catch berms or rock fall fences. This is to prevent passing vehicles from being exposed to the hazard by absorbing and dissipating the energy of the falling rock. How far a piece of falling rock will come out from a wall depends mainly on the steepness of the wall and the presence and condition of any structures. With a vertical wall, a rock fall would tend to end up near the base of the wall. However, with a sloping wall, or a wall with benches that have accumulations of material on them, the falling material will tend to bounce and be propelled farther out from the base of the wall.

Maintenance regimes should include clearing of slips or rock falls that will reduce the catchment area if left to accumulate.

For more detailed information on ground support, see section 3.

CUT AND FILL ROADS

Filled roads should be constructed in compacted, horizontal layers. When fill is placed on an existing slope, the layers should be tied-in by first removing vegetation and cutting horizontal benches into the existing slope material. Any springs or seepage areas should be collected in a drain to prevent the fill from become saturated. Erosion of fill slopes should be repaired before the condition threatens the safety of the road.

Watch for signs the ground below the road may be unstable, such as tension cracks or settling. Slopes may become unstable as they absorb rainfall, become eroded or are loaded by the weight of heavy vehicles.

5.3.15 TRAFFIC MANAGEMENT PLAN (TMP)

Regardless of the size of the site, you should produce a site specific TMP to determine where and what risks are present. TMPs are usually documented procedures which are visual in nature and identify vehicle routes, flow, access points, parking areas and other vehicle control areas.

TMPs should be updated to reflect any changes within the operation and communicate these changes to all workers and visitors as required.
This can be effectively achieved by induction, signage or tool box meetings. These will be effective if change management processes are in place.

Roads and other key features of the traffic management system within mining operations must be included in plans\(^\text{24}\).

**5.3.16 TRAFFIC SIGNAGE AND MARKINGS**

WorkSafe considers it best practice to use signage (including delineators) and line markings for drivers and pedestrians consistent with those used on public roads (where a suitable sign or marking exists). This is to ensure instructions are easily recognisable to drivers and pedestrians (a learned habit).

For more detailed information on traffic signs and markings see the New Zealand Transport Agency manuals *Ministry of Transport Signs and Markings (MOTSAM), Traffic Control Devices (TCDM)* and Code of Practice for Temporary Traffic Management (COPTTM).

Keep signs clean to make sure they are continually effective. Maintaining signs should form part of the road maintenance programme.

Use illuminated or reflective signs, markings or delineators where driving is likely to be carried out in the dark.

Use delineators suitable for the size of the largest vehicle using the road.

Consider taller delineators (road markers) in snow fall areas to make sure they are always visible where snow can drift or graders may bury them.

Signs could be used to inform drivers or pedestrians about the routes to use and also to instruct people how to behave safely (eg whether they should use protective equipment, and how) (refer Figure 32). Warning signs to show hazards along the way could also be appropriate (refer Figure 33).

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\(^{24}\) The Regulations, regulation 217 (p)
consistent with the width and smoothness of the road so the driver can operate the vehicle safely and with a reasonable level of comfort and control.

Any such speed limits should be regularly monitored and reviewed to make sure they are still appropriate. Install adequate signage where speed limits are set.

Driving conditions can vary considerably due to:

> changing weather conditions reducing visibility
> general road deterioration (reducing traction or becoming more slippery)
> volume of vehicles which accelerates wear and tear on bends and other areas where braking takes place.

Emphasise to drivers the speed limit only applies under ideal driving conditions, and they are responsible for reducing their speed to a safe level when road, weather, or other conditions are less than ideal. Sites may implement rules for temporary speed limits; for example, under fog conditions speeds are reduced.

For more detailed information on setting speed limits for on-road heavy vehicles, see the New Zealand Transport Agency publication *Heavy Vehicle Stability Guide*.

**SPEED AROUND A BEND**

Speed limits around bends can only remain the same as the straight sections of road where the superelevation and radius has been designed to allow this to happen. Where this is not possible, reduce speed limits. Speed limits will need to be sign posted accordingly.

**5.3.18 LIGHTING**

Lighting an extractives site is much more difficult than lighting a public road because of the uneven surfaces and the consequential deceptive effects of shadows.

You must provide adequate lighting to enable workers to move safely around places of work\(^\text{25}\). In addition to vehicle mounted lights, lighting should be provided:

> around plant and buildings
> on pedestrian routes
> where loading and unloading takes place
> at tip points
> at water bodies where access is required to pontoons, pumps, and so on.

Lights provided on vehicles must be sufficient to enable them to be driven safely, but additional lighting may be required for manoeuvring operations such as reversing, dumping, or at intersections.

Lights should be positioned so they do not dazzle the driver when they come around a corner or drive over a crest. When using diesel or petrol powered lighting systems you should make sure they:

> are positioned safely (eg off road lanes)
> have sufficient duration to last the shift without refuelling
> form part of the maintenance schedule.

\(^\text{25} \) Health and Safety in Employment Regulations 1995, regulation (4)(2)(e)