Guide to Road Design Part 1

Objectives of Road Design

Austroads

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Austroads

Sydney 2021

Guide to Road Design Part 1: Objectives of Road Design

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Abstract

Guide to Road Design Part 1 provides practitioners with a detailed description of the critical aspects of road design.

This Part includes the design objectives that apply to a road design project, design philosophy, context-sensitive design and the factors that influence the road design, including road design in the context of the Safe System approach, the design domain concept, design phases and processes, design considerations, design and legal liability, delivery considerations and emerging technology considerations.

Links are provided to other Austroads Guides and resources that give further guidance on design inputs.

Appendix A details processes and documentation and Appendix B offers guidance on geotechnical investigations and design.

Keywords

Road design, design objectives, road design principles, transport management, transport modes, road network, context-sensitive design, design domain, performance based design, legal liability, design considerations, factors affecting design, Safe System approach, Safe System principles, safe roads, process, procedure, documentation, international standard, design control, design brief, design development, workplace health, constructability, maintainability, design review, design verification, geotechnical, geotechnical investigation, geotechnical design, site conditions, ground water, laboratory tests, subsurface drains.

Edition 5.0 published March 2021

This Guide combines three previously published guides:

- Guide to Road Design Part 1: Introduction to Road Design 2015
- Guide to Road Design Part 2: Design Considerations 2019
- Guide to Road Design Part 8: Process and Documentation 2009.

Edition 4.0 published September 2015

Edition 3.0 published October 2010

Edition 2.0 published November 2009

Edition 1.0 published 2006

ISBN 978-1-922382-48-1

Austroads Project No. SRD6107

Austroads Publication No. AGRD01-21

Pages 189

Publisher

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About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Transport for NSW
- Department of Transport Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department for Infrastructure and Transport South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Department of Infrastructure, Transport, Regional Development and Communications
- Australian Local Government Association
- New Zealand Transport Agency.

Acknowledgements: The authors acknowledge the contributions to this report by Peter Ellis (Roads and Maritime Services), Bernard Worthington (Queensland Department of Transport and Main Roads), Richard Fanning (Department of Transport, Victoria (formerly VicRoads)), James Hughes (New Zealand Transport Agency), Michael Hogan (City of Blacktown), Andrew Baker (GHD), Sam Hatzivalsamis (Department of Infrastructure, Planning and Logistics) and Edi Winkler (Department of Planning, Transport and Infrastructure).

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1. Scope of the Guide to Road Design

1.1 Introduction

The *Guide to Road Design* (GRD) is a set of comprehensive Austroads guides developed to provide a primary national reference for the development of safe, economical and efficient road design solutions. Comprised of 14 parts, practitioners are advised to visit the Austroads website (https://www.onlinepublications.austroads.com.au) to view the latest versions of the parts as well as other guide series available.

1.2 Guide to Road Design Purpose

The GRD seeks to capture the contemporary practice of member organisations in road design.

Although local conditions and circumstances may sometimes require unique or innovative approaches to design, the bulk of works can be well accommodated by the approach outlined in the *Guide to Road Design*. However, it is recognised that member organisations may develop and publish supplementary guidelines and manuals to cover specific design situations.

Each member organisation will determine whether any other documents, including its own supplementary guidelines, take precedence over Austroads guides.

This part of the GRD contains:

- principles and objectives of road design
- network-wide design
- context-sensitive design
- design domains
- jurisdictional supplements
- process and documentation
- geotechnical investigations and design (as Appendix B).

1.3 Application of the Guide to Road Design

The GRD is aimed primarily at practitioners with responsibilities for the design of roads. The guide deals with the geometric elements of the road, together with relevant drainage and roadside considerations. The documentation is presented in the form of a number of parts covering specific aspects of the design process, with each part providing guidelines underpinned by commentaries and resource materials

It is expected that, for the experienced engineer or practitioner, the guide will provide the necessary key information and provide direction where deviations from the guidelines are required.

The guide addresses design practices across the range of road categories, from major roads to local roads, but does not address urban local access roads or low speed/low traffic environments. It also recognises that the design of roads should be based on the capabilities and behaviour of all road users, including pedestrians and cyclists, and on the performance and characteristics of vehicles. The different traffic mix and volumes, access requirements, functions and abutting developments that are typical of local roads create a different set of challenges that must be addressed in their own right. Additional guidance on the specific requirements of low trafficked roads is available in the American Association of State Highway and Transportation Officials (AASHTO) guidelines (2001) and in Giummarra (2001).

1.4 Parts of the Guide to Road Design

The Guide to Road Design has 14 parts:

Part 1: Objectives of Road Design (this part) is an overview of road design that describes the scope of the *Guide to Road Design* series, the context of the road design process, the documentation, quality management, philosophy, objectives and principles on which good design is based, and the design considerations that may be required. The use of each part, the relationships between them and their relationships to the design process are also covered. An introduction to the Safe System approach to road design has been included to alert road designers to the importance of applying such principles in every project regardless of size or complexity. Part 1 is particularly useful to designers who are new to road design or are using the *Guide to Road Design* for the first time.

Part 2: Network-wide Design provides guidance on developing network-wide safety plans, including Movement and Place principles and guidance to road managers, planners and designers to achieve improved safety outcomes with the application of consistent standards along a road corridor.

Part 3: Geometric Design provides the detailed information necessary to enable designers to develop coordinated road alignments, as well as adequate cross-sections, sight distances and other features that allow safe operation of the design traffic at the required speed.

Part 4: Intersections and Crossings: General contains guidance that provides road designers and other practitioners with information that is common to the geometric design of all at-grade intersections. The guide needs to be used in conjunction with Part 4A, Part 4B and Part 4C, which are the other parts of the *Guide to Road Design* that relate to the design of intersections.

Part 4A: Unsignalised and Signalised Intersections provides road practitioners with guidance on the detailed geometric design of all at-grade intersections (excluding roundabouts).

Part 4B: Roundabouts provides road practitioners with guidance on the detailed geometric design of roundabouts. It covers design principles and procedures, and provides guidelines for practitioners to develop safe and efficient roundabout layouts.

Part 4C: Interchanges provides road designers and other practitioners with guidance on the geometric design of freeway and motorway interchanges. It covers design considerations, design process and forms of interchanges, and provides some information on structures.

Part 5: Drainage: General and Hydrology Considerations provides road designers and other practitioners with guidance on the elements that need to be considered in the design of a drainage system. Guidance is provided on the safety aspects of stormwater flows, environmental considerations and water-sensitive treatments within a drainage system. The guide needs to be used in conjunction with Part 5A and Part 5B, which are the other two parts of the *Guide to Road Design* that relate to drainage design.

Part 5A: Drainage: Road Surface, Networks, Basins and Subsurface provides road designers and other practitioners with guidance on the design of the collection and discharge of water from road surfaces, pit and pipe systems, basins and subsurface drains. The guide needs to be used in conjunction with Part 5 and Part 5B, which are the other two parts of the *Guide to Road Design* that relate to drainage design. The guide contains information on major/minor drainage systems and the collection and discharge of road surface flows to support the operation and management of the road network.

Part 5B: Open Channels, Culverts and Floodways contains guidance on the design of open channels, culverts and floodways to support the operation and management of the road network. The guide needs to be used in conjunction with Part 5 and Part 5A, which are the other two parts of the *Guide to Road Design* that relate to drainage design. The guide provides guidance on the fundamentals of open channel, culvert and floodway flows, and includes methods to undertake the design of these drainage facilities.

Part 6: Roadside Design, Safety and Barriers provides an introduction to roadside design and in particular guidance on roadside safety and the selection and use of road safety barrier systems. It includes information to enable designers to understand the principles that lead to the design of safe roads, to identify hazards, to undertake a risk assessment process of roadside hazards, to establish the need for treatment of hazards and determine the most appropriate treatment to mitigate hazards. The guide needs to be used in conjunction with Part 6A and Part 6B, which are the other two parts of the *Guide to Road Design* that relate to roadside design.

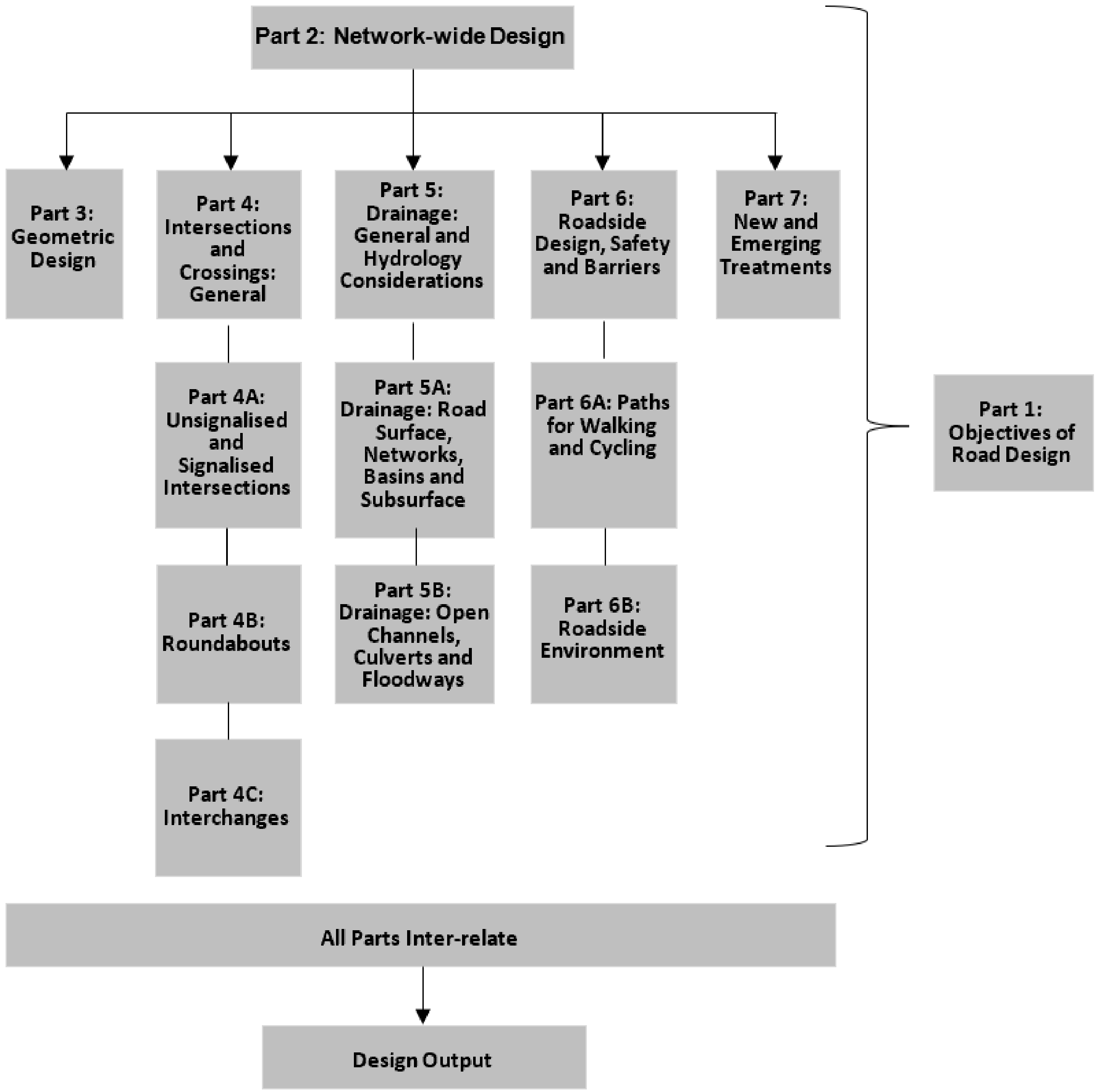
Part 6A: Paths for Walking and Cycling provides guidance for road designers and other practitioners on the design of safe pedestrian and cyclists' paths. It focuses on the geometric design of paths and its related facilities.

Part 6B: Roadside Environment describes and discusses design objectives, principles and considerations for a diverse range of roadside functions, features and facilities relating to environmental aspects, roadside amenity and roadside infrastructure. It provides guidance for road designers and other practitioners on the types of features and facilities that may need to be accommodated within a roadside. The guide needs to be used in conjunction with Part 6 and Part 6A, which are the other two parts of the *Guide to Road Design* that relate to roadside design.

Part 7: New and Emerging Treatments will provide information on emerging knowledge relating to existing design solutions. It is intended that as the evidence base of geometric criteria and performance increases, these treatments will be added to relevant parts of the *Guide to Road Design*.

Each part of the *Guide to Road Design* plays an important role in enabling a holistic and integrated approach to the design of road projects. A successful road design results from the coordination of all inputs that affect a project and all elements that combine to form the road. Designers should therefore have a sound understanding of all parts of the *Guide to Road Design* and how they relate to each other. These relationships are illustrated by the flowchart in Figure 1.1.

Figure 1.1: Flow chart of Guide to Road Design



1.5 Links to Other Guides

It is important that road designers understand the relationship between the Guide to Road Design and the other Austroads guides, including Traffic Management, Road Safety, Project Delivery, Project Evaluation, Asset Management, Pavement Technology and Bridge Technology. All current Austroads publications are available from the Austroads website www.austroads.com.au.

In particular, the Guide to Road Safety and the Guide to Traffic Management complement the Guide to Road Design series.

1.5.1 Guide to Road Safety

The aim of the *Guide to Road Safety* is to provide all Austroads members with the tools to fulfil the key objective of the continuing reduction in road trauma. The series examines road crash costs and road agencies' duty of care to provide safe travel.

The advantages and disadvantages of different ways of measuring road safety are discussed, and these methods are used to illustrate progress in road safety in Austroads' member jurisdictions in recent years.

The Safe System approach as the guiding principle for road safety management is explained, along with the merits of an evidence-based approach to selected road safety countermeasures.

Safe System principles are the basis for road safety programs in Australia and New Zealand. Safe System seeks to ensure that no road user is subject to forces in a collision which will result in death or an injury from which they cannot recover. It recognises that road user error cannot be completely eliminated (although it can be reduced), so the road transport system must therefore be designed to make collisions survivable. This is achieved through a combination of design and maintenance of roads and roadsides, design of vehicles and their safety equipment, speed management, and having alert and compliant road users (Austroads 2013d).

1.5.2 Guide to Traffic Management

Traffic management is the organisation, arrangement, guidance and control of both stationary and moving traffic, including pedestrians, cyclists and all types of vehicles. It addresses primarily the volume, composition and speed of the traffic either throughout the road network or in one or more parts of the network. The *Guide to Traffic Management* series (Austroads 2020g) provides comprehensive guidance for practitioners on network operations planning, traffic flow theory, the allocation of road space, the type of intersections to be designed and how the traffic flows throughout a network safely and efficiently. The consideration and choice of appropriate treatments may be an iterative process between practitioners, with geometric constraints often becoming the controlling parameters for the selection of traffic management treatments.

The series also provides guidance on traffic management for local areas, activity centres, parking and land use developments, and on traffic operations and traffic control and communication devices.

1.5.3 Terminology

The *Austroads Glossary of Terms* (Austroads 2015) provides a comprehensive account of terms that relate to the guides.

1.6 Jurisdictional Supplements

New Zealand and Australian states, territories and some councils may have local policies, strategies, laws and by-laws which may impact on the guidelines provided e.g. the guides may provide a range of values, but a jurisdictional supplement may specify a specific value.

The following are links to road agencies with amendments to or additional content to the Austroads *Guide to Road Design*. Some must be read in conjunction with the guides, while others may take precedence.

1.6.1 VicRoads, Victoria

The Business and Industry section of VicRoads website contains technical documents for road design and management, information about the heavy vehicle industry and technical services and is located at https://www.vicroads.vic.gov.au/business-and-industry/.

Road design supplements can be found at https://www.vicroads.vic.gov.au/business-and-industry/technical-publications/road-design

Pavements, geotechnical and materials https://www.vicroads.vic.gov.au/business-and-industry/technical-publications/pavements-geotechnical-and-materials

Contract specifications https://www.vicroads.vic.gov.au/business-and-industry/technical-publications/contract-specifications

1.6.2 Department of Transport and Main Roads (TMR), Queensland

Supplements form parts of an overall document called the *Road Planning and Design Manual* – 2nd edition. Links to the individual supplements to the *Guide to Road Design,* and *Guide to Road Tunnels* are found via the link https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-planning-and-design-manual-2nd-edition

Note: Links to individual supplements are not included as they will become superseded as each guide is updated (the same applies to the link above when a new edition is published because the edition number is part of the web link).

1.6.3 Roads and Maritime Services (Roads and Maritime), New South Wales

To address specific issues concerning the design, construction, maintenance, operation and safety of road network issues in NSW, Roads and Maritime Services has produced a range of mandatory Roads and Maritime Services Austroads Supplements. These can be found via the link https://www.rms.nsw.gov.au/business-industry/partners-suppliers/document-types/supplements-austroads-guides/index.html

The supplements to the *Guide the Road Design* can be found via https://www.rms.nsw.gov.au/business-industry/partners-suppliers/document-types/supplements-austroads-guides/road-design.html.

1.6.4 Main Roads, Western Australia

Main Roads has produced jurisdictional supplements for the Austroads *Guide to Road Design* series of documents and other relevant road design information e.g. Extended Design Domain (EDD). https://www.mainroads.wa.gov.au/technical-commercial/technical-library

1.6.5 Department of Planning, Transport and Infrastructure (DPTI), South Australia

The Department of Planning, Transport and Infrastructure (DPTI) do not produce an equivalent supplement to the Austroads guides. They do, however, publish a number of documents which incorporate elements that vary from the guides. The following link directs to the home of the Technical Standards and Guidelines (Road & Marine), https://dpti.sa.gov.au/standards

Documents focused on road design, design development, process and documentation can be found at https://www.dpti.sa.gov.au/standards/roads-all and https://dpti.sa.gov.au/contractor_documents/masterspecifications

1.6.6 Department of State Growth (DSG), Tasmania

The Department of State Growth's (DSG) transport area generally follows the guides except where the guides 'conflict with specific provisions of the [Professional Services Specification] PSS, the specific provision of the PSS shall prevail'. https://www.transport.tas.gov.au/__data/assets/pdf_file/0014/111425/D1_-_Road_Design_-_June_2012.PDF

Professional Services Specifications (including the specific road design link above) can be found by following the link below. This includes but is not limited to planning, design, risk management and design review reporting requirements. Many of these documents are currently under review https://www.transport.tas.gov.au/road/contractor/specifications/professional-services

Road Design standards, including the process for acceptance of non-compliant design elements are contained in the following link, https://www.transport.tas.gov.au/__data/assets/pdf_file/0020/111449/T3_-_Road_Design_Standards_-_July_2012.pdf

1.6.7 Transport Canberra and City Services Directorate, Canberra

Transport Canberra and City Services have largely adopted the guides. Broadly, links to Standards, Codes and Guidelines can be found at the following link,
https://www.tccs.act.gov.au/Development_and_Project_Support/standards-codes-and-guidelines

Supplement to the Guide to Road Design (set)
https://www.tccs.act.gov.au/__data/assets/pdf_file/0010/398422/ACT_TRIS_02_Road_Design.pdf

1.6.8 Department of Infrastructure, Planning and Logistics, Northern Territory

The Northern Territory government has produced a more generic set of standard specifications which contain the latest in both policy and regional requirements to ensure that assets constructed for the Northern Territory government reflect best industry standards.

https://dipl.nt.gov.au/industry/technical-standards-guidelines-and-specifications

https://nt.gov.au/driving/management

1.6.9 New Zealand Transport Agency

https://www.nzta.govt.nz/resources/state-highway-geometric-design-manual/shgdm/

https://www.nzta.govt.nz/roads-and-rail/road-engineering/geometric-design/supplementary-guidance/

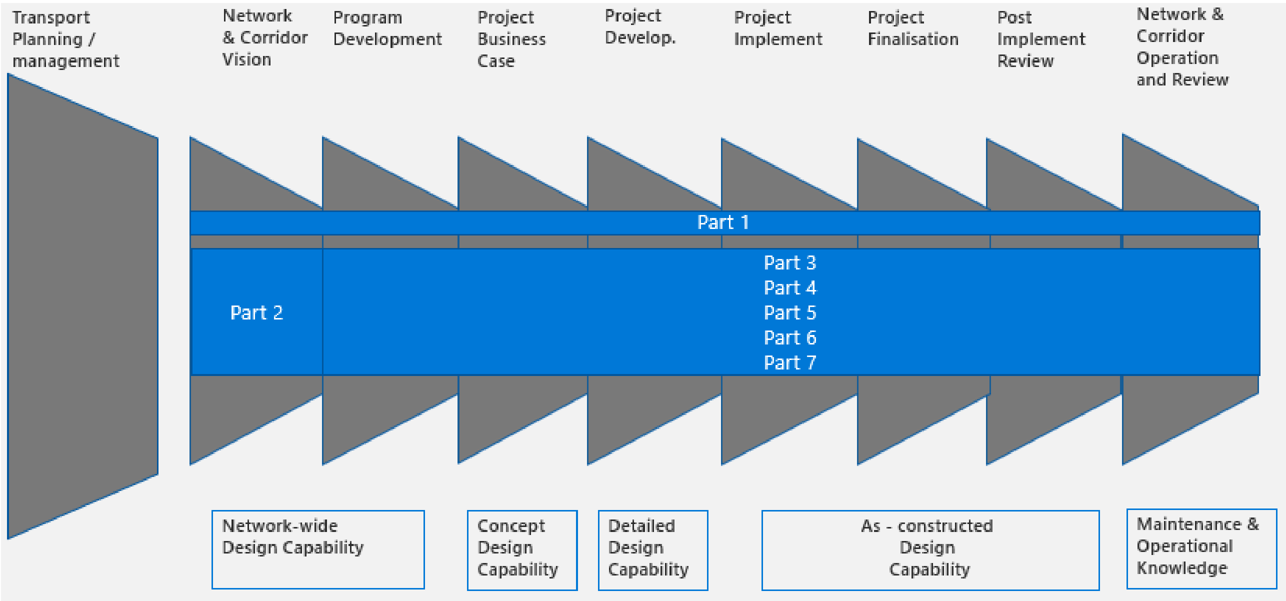
The above links are not an extensive list or review of where road agencies vary from the guides but provide direction for the practitioner to some of the required road design, design considerations and process and documentation links for road designs. Practitioners must ensure all required documentation has been sought, prepared and referenced in accordance with the requirements of the project and the relevant jurisdiction.

2. Road Design Across the Transport Management System

2.1 Road Management Phase Process

Road design plays a key role in almost all aspects of the road management process. The stages of the road management process and how the parts of the GRD align with this process are outlined in Figure 2.1 below.

Figure 2.1: Role of the GRD parts within the road management phase process



The philosophy, principles and objectives set out in the suite of Austroads guides underpin the creation of a successful, site-specific design solution.

Designers choose the features of the road and dimensions of its elements based on technical guides, calculations, and their own experience and judgement. However, a very important principle in choosing these dimensions is to avoid combinations of minimum or limiting values of different design elements as this has the potential to quickly reduce the inherent safety of the overall solution.

The practice of good road design, especially under constraints, involves judgement as well as calculation. It involves compromises between conflicting goals. Experience assists the designer to arrive at an appropriate balance that cannot be met by a system of mathematical rules alone. The Austroads guides give ranges of values within which the designer has reasonable flexibility to produce an appropriate design solution for a specific problem, whilst retaining a reasonable overall level of uniformity.

Some key areas that provide a context for the road design process are discussed in this section.

2.1.1 Road Planning

Projects requiring road design process and principles may range from minor improvements to small sections of existing roads, to restoration projects that improve road cross-sections while retaining existing alignments, or to major greenfields design of arterial roads as part of significant regional or inter-regional development. At one extreme, the work may have no significant environmental or social impacts and involve minimal interaction with other agencies. At the other, the road agency may be but one party in a broad or inter-government activity. The inter-relationship between land use and transport planning is an important consideration in any planning scheme – they should be complementary. The upgrade of existing roads or design of new road infrastructure should therefore be in accordance with local planning objectives as well as with the transportation and traffic management strategies relevant to the particular road corridor or link. There should be consideration of national, state and local road safety strategies and the interests of all road user groups.

The location and function of a road within the built and natural environment will affect the objectives and strategies to be adopted and will influence all aspects of the design process. Information on these aspects can be found in the *Guide to Traffic Management* and the *Australian Transport Assessment and Planning (ATAP) Guidelines*, in particular the guidance on integrated transport and land use planning (ITLUP).

Familiarity with road design principles is important in road planning activities, especially during concept development, for the purposes of assessing options in terms of traffic service, road safety, environmental impact and other important factors. Consideration should be given to undertaking proactive safety risk identifications such road safety audits (RSA) at various points throughout the design and implementation processes for a project. First developed in the United Kingdom, Australia and New Zealand, RSA has the proven potential to improve the safety of both proposed and existing facilities (see Section 2.2.3 for detailed description of Road Safety Audits).

The design of roads may also be influenced by the investment strategy for the road network or a particular project, as well as the costs and issues associated with options or parts of options. The design process is often iterative as the effects, costs and benefits of various options are explored. For example, the geotechnical properties of soil, the nature of a river crossing or the level of interaction between road user groups may all influence the design. It is therefore essential that effective communication take place between persons responsible for delivering a project (e.g. project manager, project team members and client) and the road designer. A road designer should be clear on the project objectives, for example is the primary focus about pedestrian safety, traffic amenity for heavy vehicles or seeking to remove conflicting manoeuvres at an intersection, or any combination of those objectives.

Final approval of a project may rest with a person or persons removed from the design process. The rationale for the preferred design should be clearly documented, including the scope, cost and consequences of viable alternative solutions. This could include the degree of take-up or adoption of Safe System elements incorporated into the design, and the manner of addressing public concerns which may have been the basis for the project conception.

2.2 Network Considerations and Outcomes

2.2.1 The Safe System Approach

Safety is a primary objective in road design, and is pursued in accordance with the Safe System approach, which is a guiding philosophy that has been adopted by leading road safety nations and has been a foundation of the road safety strategies and action plans adopted in both Australia and New Zealand since 2004. This approach has been reiterated in the current strategy documents for each country (prepared by the Australian Transport Council 2011 and Ministry of Transport 2010).

The NZ Transport Agency (2012) succinctly describes this approach to road safety as follows:

> *The Safe System approach works on the principle that it is not acceptable for a road user to be killed or seriously injured if they make a mistake.*
>
> *The Safe System approach aims to create a forgiving road system based on these four principles:*
>
> 1. *People make mistakes – People make mistakes and some crashes are inevitable.*
> 2. *People are vulnerable – Our bodies have a limited ability to withstand crash forces without being seriously injured or killed.*
> 3. *We need to share responsibility – System designers and people who use the roads must all share responsibility for creating a road system where crash forces do not result in death or serious injury.*
> 4. *We need to strengthen all parts of the system – We need to improve the safety of all parts of the system – roads and roadsides, speeds, vehicles, and road use so that if one part fails, other parts will still protect the people involved.*
>
> *Under a Safe System, designers create and operate a transport system where people are protected from death and serious injury.*

The Safe System approach in Australia and New Zealand has four pillars that underpin the above principles:

1. **Safe roads** – that are predictable and forgiving of mistakes. They are self-explaining in that their design encourages safe travel speeds.
2. **Safe speeds** – travel speeds suit the function and level of safety of the road. People understand and comply with the speed limits and drive to the conditions.
3. **Safe vehicles** – that prevent crashes and protect road users, including pedestrians and cyclists, in the event of a crash.
4. **Safe road use** – road users that are skilled and competent, alert and unimpaired. They comply with road rules, take steps to improve safety, and demand and expect safety improvements

A fifth pillar, post-crash response, was introduced by the United Nations in 2010 (World Health Organization 2011) but is not yet reflected in many portrayals of the Safe System. It is noted, however, that post-crash response is also included as part of the current NSW and SA state road safety strategies but only as a supporting activity (Towards Safe System Infrastructure: A Compendium of Current Knowledge Austroads 2018).

A conceptual representation of the Safe System approach is illustrated in Figure 2.2.

Figure 2.2: Conceptual representation of the Safe System

Source: Austroads (2019b).

In the context of designing and providing a safer road environment, the Safe System approach aims to ensure that potential collisions are avoided and, if they occur, that the crash impact forces do not exceed human tolerance. On rural roads and major arterials, multi-vehicle and single-vehicle crashes are the prime concern, whereas on urban local roads pedestrian activity, and the potential for vehicle-pedestrian conflicts, is greatest. Pedestrians are particularly vulnerable to serious injury. Design considerations for local roads must therefore strive to ensure that these conflicts are avoided and that design speeds are commensurate with potential impact speeds that are survivable (see also Section 2.3.3).

Without guaranteeing absolute safety, a 'safe road environment' is one in which road users can successfully negotiate road alignments and potential conflicts with other road users, and which provides a forgiving roadside environment for errant vehicles. It recognises the realities and limitations of human decision-making – in other words, it does not place demands upon the driver, or any other road user, which are beyond their ability to manage, or outside normal road user expectations. Such a safe road environment will be achieved if it is designed and managed so that it provides:

- a generally consistent design standard
- effective transitions where a reduction in standard is necessary (i.e. there should be no 'surprises' in road design or traffic control, and the design should match road user expectations)
- a controlled release of relevant information (the design matches the information processing abilities of drivers)
- repeated information, where pertinent, to emphasise increased risk
- for the safety needs of all road users.

Applying the principles of risk management and the Safe System approach, a safe road should:

- be 'self-explaining' to allow road users to readily comprehend the type of road and what could be expected in terms of the elements of the design
- warn road users of any substandard or unusual features
- inform road users of conditions to be encountered
- guide road users through unusual sections
- control road users passage through conflict points or conflict sections
- be forgiving of errant or inappropriate behaviour.

Designing a road to these principles is not the same as designing a road which simply meets a set of recommended values. A road designed to meet a set of recommended values is not necessarily safe and a road which, in some details, fails to meet these values is not necessarily unsafe. There is no substitute for the application of sound engineering experience and judgement.

2.2.2 Design Considerations

Most design choices affect the expected crash likelihood, frequency, severity or a combination of these variables. Some design choices are made from a continuum of values (e.g. median width, grade or sight distance). The change in safety corresponding to a change in these values is also continuously variable. For example, the narrower the median, steeper the grade or shorter the sight distance, the less safe the road will be. Some safety improvements are not gradual. For example, the decision to illuminate a road will cause an immediate, significant drop in night-time crashes and a (usually smaller) increase in daytime crashes because of the introduction of light poles and the barriers protecting them. In this case, a road designer should ask what more can be done to address the severity of the crashes that may continue to occur and then set about incorporating an appropriate measure to reduce crash severity.

Design choices leading to safety improvements usually cost money. Conversely, cost savings through electing to use lower design domain values can increase crash frequency, severity or both. When choosing the value for a design parameter from a range of values, a balance must be found between increasing cost and diminishing safety improvements, as the value of the parameter changes. There comes a point at which the safety benefits are so small that money can be spent to better effect elsewhere. When the design choice is to include or omit a feature, a safety gain is bought at a discrete cost. In both circumstances, rational design involves the determination of the potential safety gains, the determination of the attendant costs, and the balancing of costs and safety gains.

Expenditure of public money is required for the improvement of facilities to reduce the probability of collisions. However, unlimited funds are never available, and spending should be concentrated in areas where the greatest safety improvements can be realised at justifiable costs, noting that costs may be in the form of, for example, environmental impact, not only money. It is here that the Safe System approach can assist a road designer in making cost-efficient decisions. For instance, measures to reduce crash severity may be a more affordable and practical option than measures to prevent all crashes from occurring. In such circumstances it can be argued that a higher level of safety has been achieved on the road design to the benefit of the community, even though some crashes can still be expected to occur.

To make an appropriate design choice affecting the future safety of a road, the designer should use the best available information. Research into the relationship between crash frequency and road design parameters has been undertaken in Australia, New Zealand and overseas in recent years, which led to the development of analytical tools to evaluate crash risk and the effect of treatment options on crash frequency. This information is available for the road designer to consider in relation to specific road design solutions. Designers of the past, without benefit of this knowledge, often relied on geometric design standards, based on laws of physics, without the necessary data to adequately assess the safety consequences. Reliance on guidelines will not necessarily ensure that an appropriate level of safety has been built into a road.

2.2.3 Designing for Safety

Virtually all elements of road design have safety implicitly included in their derivation, although this may not necessarily be spelt out. For example, horizontal and vertical alignment designs are based on sight distance and lateral acceleration considerations which are, in turn, derived using the operating speed and the performance characteristics of vehicles to allow for safe operation.

The Safe System approach encourages road designers to consider more deeply the implications of their emerging design solution; by designing a road environment that limits crash impact speeds and which acknowledge the limits of the human body, road designers can achieve greater improvements in road safety.

Three areas are particularly considered in the safety performance of roads, namely intersections, mid-block conditions and the roadside environment.

Intersections

Intersections present multiple conflict points for road users and their design and control are major factors in improving road safety. In general, an intersection should be obvious and unambiguous and allow good visibility of traffic control devices and other road users. Care must be taken to select the most appropriate type of intersection in terms of traffic control (priority controlled, roundabout, signalised etc.), as each type has its strengths and weaknesses. Good design will harmonise the geometric layout with traffic control requirements and will minimise both the number of traffic conflict points and the magnitude of conflict areas.

An intersection design must be viewed from the perspective of each road user group. The needs of drivers differ significantly from pedestrians and cyclists; some intersection types may address vehicle driver/passenger needs very effectively, but at the same time may present a higher risk to the vulnerable road user groups.

The main factors that affect intersection safety include:

- safe approach speed
- number of legs
- angle of intersection
- sight distance
- observation angle
- alignment
- auxiliary/turning lanes
- channelization
- intersection control
- friction or pavement skid resistance
- turning radii
- traffic lane and shoulder widths
- property access
- signing and road marking
- lighting
- traffic volume
- interaction between user groups
- driver behaviour
- driver alertness.

For information on the traffic engineering requirements for intersection design, refer to the *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings* (Austroads 2020e).

For information on detailed geometric design of intersections, refer to the *Guide to Road Design Part 4: Intersections and Crossings* (Austroads 2017a).

Mid-block

Mid-block safety should be considered during the design phase. Although the term ‘mid-block’ has strong urban connotations, the principles apply equally to sections of rural roads between intersections.

On-road safety is influenced by horizontal and vertical alignment and their effect on such things as sight distances and overtaking opportunities, by the dimensions of cross-section elements, by the degree of access control and a range of other factors. Good design will provide road users with geometry that is both consistent along a given route and consistent with other roads of the same type, so that driving requirements can be correctly anticipated.

The factors that influence mid-block safety include:

- vehicle speeds and speed differential between vehicles
- pavement surface
- delineation
- traffic lane width
- shoulder width
- horizontal and vertical geometry
- degree of access control
- overtaking opportunities
- sight distance
- roadside hazards
- traffic volume
- interaction between user groups
- driver behaviour
- driver alertness.

For information on traffic engineering aspects of mid-block design, refer to the *Guide to Traffic Management Part 5: Road Management* (Austroads 2020d).

For detailed information on the geometric design of mid-block sections, refer to the *Guide to Road Design Part 3: Geometric Design* (Austroads 2016a).

Roadside

Roadside safety typically relates to the area adjacent to the traffic lane where an errant vehicle can recover. When drivers lose control and vehicles leave the road, there is a risk of injury and damage due to collisions with unyielding objects (e.g. trees and poles) or non-traversable features (e.g. drains, berms or rough surfaces) that may cause the vehicle to vault (i.e. become airborne), roll over or stop abruptly.

The roadside areas may need to provide for other road user activity such as pedestrians, cyclists, emergency breakdown and rest areas. The interaction of these activities with road traffic and the risk posed by errant vehicles must be considered in the development of road designs.

Notwithstanding that there are physical, environmental and economic constraints, the preferred treatments of roadside hazards (in a hierarchy-of-control risk management order) are:

- removal
- relocation to reduce the chance of them being hit
- redesign so that they can be safely traversed
- redesign to be frangible or break away, or to otherwise reduce severity
- shield with a safety barrier or impact attenuator
- delineate the hazard if the above alternatives are not appropriate.

It must be recognised that safety barriers are also potential hazards that often have a higher probability of being impacted than the object they are shielding but have a lower severity of impact. While this crash severity reduction is core to the Safe System approach, the application of a road safety barrier should not automatically be considered to meet Safe System objectives. Research and crash experience have shown that safety barrier performance to reduce crash severity varies depending on the type of barrier, its application in the roadside area and the road user group impacting the barrier.

For information on roadside safety and design, reference should be made to the *Guide to Road Design Part 6: Roadside Design, Safety and Barriers* (Austroads 2020a), together with the *Guide to Road Safety Part 9: Roadside Hazard Management* (Austroads 2008).

Road safety audits

A road safety audit is a formal, robust technical assessment of road safety risks associated with road transport projects. Road safety audits:

- are completed by independent and qualified audit teams
- are completed by applying Safe System principles while seeking to ensure that roads will operate as safely as practicable by eliminating fatal and serious injury crash potential
- consider the safety of all road users (unless specified within the audit brief)
- can be conducted on proposed or existing roads.

The road safety audit process is a valuable tool to ensure that safety aspects are ‘built in’ to a project from conception rather than attempting to ‘add them on’ at an advanced stage or even retrofit treatments after a crash history develops. A road safety audit serves to review all aspects of the project from concept, design, and during construction and post-construction stages.

The objectives are to identify potential safety problems for road users and others affected by a road project, and to ensure that measures to eliminate or reduce the problems are considered. That is achieved by removing elements with high collision potential at the planning or design stages, and by mitigating the effects of remaining or existing problems by the inclusion of collision reduction features, such as traffic control devices.

For new designs, road safety audit procedures can be applied throughout the design process and become an integral part of the development of the road design. Safety experts work with designers to provide guidance at all levels of the project development process, from the planning stage to the formal opening of the facility. By integrating road safety considerations with the design process, cost-effective opportunities to improve safety in a design can be identified early in the design process and can more easily be incorporated into the work.

Guidelines on the conduct of road safety audits are available in Austroads (2019b) and NZ Transport Agency (2013).

Safe System assessment

The first action item from the Australian National Road Safety Strategy (NRSS; Australian Transport Council 2011) is to ensure that all new road projects consider Safe System principles, and an assessment needs to be undertaken to confirm that this has been done. The underlying principle of the Safe System is that humans are fallible, and sooner or later mistakes (and hence crashes) will happen. When they do, the system should be designed to prevent a fatal or serious injury from occurring.

A Safe System assessment will identify the areas of the project where there is a high risk of a fatal and/or serious injury. Modifications to the project are then identified to address these high-risk areas to ultimately align with the Safe System principles. To measure how well a project aligns with the Safe System principles, a Safe System matrix has been developed which assesses seven major crash types against the exposure to that crash risk, the likelihood of it occurring and the severity of the crash should it occur.

Whilst the Safe System approach has been adopted by Australia and New Zealand since 2004, there has been difficulty amongst practitioners integrating Safe System into their road infrastructure projects. Austroads has since produced a practitioner assessment tool process to assist in the methodical consideration of Safe System objectives in road infrastructure projects. This can be found in Austroads Research Report AP-R509-16, *Safe System Assessment Framework*. Furthermore, some jurisdictions have their own guidelines and requirements for Safe System assessments, and practitioners should contact their local jurisdiction to ensure compliance.

It should be noted that a Safe System assessment does not replace a road safety audit. A Safe System assessment evaluates whether a project aligns with the Safe System approach, whereas a road safety audit identifies road safety issues regardless of the potential crash severity.

Star Rating for design

Star Ratings provide a simple and objective measure of the level of safety provided by a road’s design. It involves an assessment of road infrastructure attributes that are known to have an impact on the likelihood of a crash and its severity. Based on this, between 1 and 5-stars are awarded depending on the level of safety which is ‘built-in’ to the road, with 1 star being the least safe and 5 stars being the safest. Star Ratings can be determined for both an existing road or during the design phase. The methodology for a Star Rating assessment is provided by the International Road Assessment Programme (iRAP).

The National Road Safety Action Plan 2018-2020 identified nine priority actions to be implemented during this period, two of which have direct implications to the design of a road, specifically the Star Rating of a road:

- Priority Action 2: Target infrastructure funding towards safety-focused initiatives to reduce trauma on regional roads
- Priority Action 3: Implement safety treatments to reduce trauma from crashes at urban intersections

The collective aim of these two Priority Actions is to improve the Star Ratings across the whole road network, with the aim to achieve 3-Star Ratings or better for 80% of travel on state roads, including a minimum of 90% of travel on national highways (Australian Transport Council 2018). With this in mind, all new designs should aim to have a minimum 3-Star Rating.

2.2.4 Nature and Magnitude of Transport Demand

The prime requirement for any road is to enable the transportation of people and goods in a safe and efficient manner. This of course requires an estimate of the traffic that is expected to use it, in terms of absolute volume, type of vehicles, and time distribution.

Given the long-term nature of any road investment, traffic estimates will commonly cover a period of 20 to 40 years. Many factors will impact the actual traffic growth compared to the best estimates that can be made, including local and regional land developments, demographic changes, the broad economy, and technological changes in the vehicle fleet.

Future traffic flow for roads is determined through traffic forecasting, either by estimating growth from historical data in the case of rural roads or by the use of traffic modelling techniques and computer software packages for urban road networks.

Estimates of traffic flow for particular road user groups are also important, as it may be necessary to provide special facilities for public transport, cyclists and pedestrians in urban corridors and freight/over dimensional movements may determine design standards for use in some rural corridors.

Information on the estimation of traffic volumes is contained in the *Guide to Traffic Management Part 3: Traffic Studies and Analysis* (Austroads 2020b). Reference can also be made to the US *Highway Capacity Manual* (Transportation Research Board 2010).

2.2.5 Strategic Fit

As well as satisfying local requirements, the objectives for a road project should support transportation outcomes required by governments (federal, state and local) and the community. The required outcomes may be reflected in:

- government policies
- investment strategies
- planning schemes
- network operation plans.

These outcomes may influence the function that a road is required to perform within the road network, and hence its design objectives.

Relevant government policies may be transport-specific, for example, addressing the desired balance between road-based transport and other modes of people or goods movement, or between private and public transport for passenger travel. Alternatively, they may be more general, for example, directed towards desired patterns of land use and economic development in urban and regional areas.

Investment strategies may similarly be transport-specific or broad. Broad strategies may be concerned with the allocation of funding between different economic sectors such as education, health, national security and transport, while transport-specific strategies may address such questions as the roles of the public and private sectors in road or rail infrastructure development, the distribution of government funding between different transport modes, or the relative merits of investing in transport demand management schemes as opposed to infrastructure expansion.

Road project objectives may also reflect and support strategic transportation and development plans for the country, state, city or area through which the road passes. Ideally, planning will integrate consideration of transport, land use and environmental objectives and will address multi-modal issues, which are often outlined in network operation plans. Network operation planning, as described in Part 4 of Austroads *Guide to Traffic Management* (Austroads 2020c), can define the context in which the road will operate, particularly with respect to Intelligent Transport Systems (ITS) operations, and therefore aid in the design of the road by providing guidance on how to design the road for its operations. Further discussion about planning integration and road project objectives is provided in the Integrated Transport and Land Use Planning (ITLUP) part of the Australian Transport Assessment and Planning (ATAP) Guidelines (Transport and Infrastructure Council 2016). These aspects, in the context of road design, are briefly discussed below.

- Policies, investment strategies and planning schemes will influence objectives for both the planning and design of road projects through their implications for such aspects as the spatial distribution of transport demand, feasible corridor locations, required traffic capacities, freight routes and on-road public transport.

- Project objectives must relate specifically to the issues or problems being addressed. It is important to evaluate design options for road projects, and the assessment criteria used must have the capacity to address a project's specific objectives and its impacts. It is desirable that assessment criteria include all economic, environmental and social consequences of each option. 'Triple bottom line' is a term commonly used to describe the joint consideration of these aspects (refer to the *Guide to Project Evaluation*).

Designing for operations

A road is one element of a transport system, and the road operates in the natural and built environment to meet a range of expectations of the users and the broader community. The design of the road cannot be carried out in isolation but must be sensitive to the context in which the road will operate. This is captured in Section 4.7 by outlining the various factors affecting design decisions.

To maximise the safety, reliability, and efficiency of the network, it is crucial that roads are designed to better manage demand and respond to incidents and other events. Designing for operations improves the integration of operational considerations throughout the project development life cycle (refer to Federal Highway Administration (FHWA) (2013)).

Managed motorways

The best urban motorway performance outcomes can only be achieved with a holistic and multidisciplinary understanding of traffic analysis, road design principles and traffic engineering theory. This must then be combined with accurate and reliable data, advanced control systems, Intelligent Transport Systems (ITS) and electrical and electronic devices supported by Information and Communication Technologies (ICT). These tools and disciplines are integrated to provide a single optimised system to manage motorway traffic flows (mainline, entry ramp access, exit ramps and interchanges) in near real-time, as well as speed limits, lane use and traveller information. This ensures motorway infrastructure and assets deliver their intended economic and strategic performance (VicRoads 2019).

For further information and guidance on Managed Motorway Design see VicRoads: https://www.vicroads.vic.gov.au/traffic-and-road-use/traffic-management/managed-motorways/managed-motorway-design and Austroads Guide to Smart Motorways

2.3 Multi-Modal Considerations

Roads need to cater for a variety of travel modes, and each needs to be considered in the development of a road project.

2.3.1 Freight

On routes with a significant freight task, it is important to cater for the special requirements of heavy vehicles. Modest grades may be warranted to enable heavy vehicles to maintain speeds, and longer overtaking lanes should be considered to allow long vehicles with small speed differentials to safely overtake. Intersections and property accesses should be designed to enable access to large freight vehicles where appropriate.

Overall planning may also indicate the need for rest stops and for the provision of service facilities or areas to break up long vehicles prior to entering more restricted or densely trafficked environments.

2.3.2 Public Transport

Most urban projects require specific provision for public transport usage. This may involve reservation of corridors for light or heavy rail, provision for modal interchanges in or adjacent to the road reserve, or dedicated bus or high occupancy vehicle (HOV) lanes. HOV lanes are also commonly referred to as transit lanes, which are defined as traffic lanes set aside for the use of buses, motorcycles, taxis, turning vehicles and vehicles carrying a specified minimum number of vehicles. HOV/transit lanes may be provided on freeways and other roadways for the exclusive use of buses and other high occupancy vehicles so they can bypass peak-period congestion on the remaining lanes. Increases in ridesharing can be gained from this option when the time savings are significant.

2.3.3 Provision for Cyclists and Pedestrians

In recent years there have been significant developments in policy and strategic planning initiatives aimed at giving greater recognition to pedestrians in transport planning, particularly in urban areas. This has arisen from policy settings in the transport and health sectors recognising the need to move towards more sustainable forms of transport (by foot, bicycle or public transport) and towards healthier activity (walking, cycling) by the community generally. This has led to recognition of the need for planning and designing a road network which caters for the potential increase in active travel, and for providing facilities for safe pedestrian activity.

Any road design project must consider the needs of all relevant road users. This will often include cyclists, pedestrians and other non-motorised traffic of all age groups.

Cyclists and pedestrians are particularly vulnerable road users. Design for such users will seek to facilitate their movements by separating them from motor vehicles in time and space:

- along road reserves, either on the road carriageway, by providing on-road bicycle lanes for cyclists, or on roadside facilities such as footpaths and shared-use paths
- across road carriageways at intersections or at mid-block locations, with signalised and non-signalised crossings
- along off-road facilities, such as exclusive or shared bicycle and walking paths.

It is not always possible, or desirable, to clearly separate vehicular and pedestrian activity. In some instances, the provision of shared areas is a preferred approach, utilising facilities such as ‘shared zones’ and ‘shared spaces’. Further discussion of these facilities is given in the *Guide to Traffic Management Parts 5, 6 and 7* (Austroads 2020d, 2020e, 2020f) and the *Guide to Road Design Part 6A* (Austroads 2017b).

2.3.4 Provision for Motorcyclists

Motorcyclists are more vulnerable than most other road users due to their unique operating characteristics. For this reason, it is most important that motorcyclists’ safety needs are considered during the design, construction, maintenance and management of roads. Consequently, road designers should appreciate that some design issues or situations that may arise could place motorcyclists at greater risk than drivers of other types of vehicles. The Austroads Research Report *AP-R515-16 Infrastructure Improvements to Reduce Motorcycle Casualties* (Austroads 2016b) provides detailed information regarding how design choices for midblock and intersections can influence motorcycle crash risk. Table 2.1 summarises design issues and good practices that are relevant to motorcyclist safety.

Table 2.1: Design issues and good practices that influence motorcyclist safety

Issue	General good practice for all road users and most important in catering for the special needs of motorcyclists
Visibility	More critical for motorcycles to reduce the incidence of hard braking. Achieve and maintain sight distance standards. Clear vegetation from sight lines on inside of curves.
Recognition of layout and clear definition of vehicle paths	Avoid surprises or dangerous combinations of geometric elements. Maintain a high standard of delineation and pavement markings. Do not use kerbing colours which blend in, especially on islands and protrusions.
Adverse crossfall	Avoid it as much as possible. Where unavoidable keep within limits of design guidelines.
Compound curves	Avoid using them (warning signs will not overcome the problem).
Skid resistance	Provide adequate skid resistance especially in areas where braking and manoeuvring is frequently required. Provide a surface which maintains traction in front of barriers. Design intersections and driveways so that drainage water does not wash gravel and debris onto road surface.
Aquaplaning	Design the alignment and/or drainage to drain water away promptly.
Lane widening on curves	Important to follow established guidelines as motorcycles lean into curves.
Road patches – unsealed patches on sealed roads	Creates a slick surface when wet. Must give standard warning.
Road patches – sealed, surface screenings	Gravel leads to loss of traction. Must give standard warning. Sweep gravel off road.
Parallel grooving	Do not use it. Apply transverse grooving.
Pavement markings (paint or long life)	Adopt pavement markings with the same skid resistance as the rest of the road. Do not use large areas of it in traffic lanes.
Rubberised crack sealant	Very slick surface; needs additive for same skid resistance as the rest of the road. Avoid use where it can be mistaken for lane lines at night or in the wet.
Pavers within the carriageway	Do not use them in high traffic areas where breaking up of pavers is likely. Confine them to local roads.
Gravel/loose material on road	It is normal for gravel to build up on roads. Ensure regular sweeping. Avoid layouts which lead to it accumulating. Avoid loose material on curves and corners.
Corrugated and uneven roads	Avoid changes in the road surface texture or shape in braking areas, and on curves and corners. Repair or warn where corrugations can be unexpected.
Pavement edge drop offs	More critical for motorcyclists as they have no second pair of tyres to keep traction. Maintain shoulder pavement level or provide smooth transition. Provide sealed shoulders.
Spray off roads in wet weather	More critical for motorcyclists as they have no windscreen wipers. Provide adequate surface drainage. Use low spray surface texture.
Frost or ice conditions	Warn of slippery conditions when frosty or where ice may be present.
Roadside furniture	Provide adequate clearance from carriageway to posts and poles (especially where motorcycles need to lean into curves). Minimise the number of posts and poles. Consider soft environmental elements (e.g. hedges) between the road and roadside objects. Provide adequate maintenance and replacement of retroreflective devices (signs and delineation). Delineate the back of signs at critical edges of islands. Do not use posts or rails which have sharp edges, protrusions or parts which can entrap a motorcyclist.

3. Principles and Objectives of Road Design

3.1 Definition of Road Design

Design is the process of originating and developing a plan for an aesthetic and/or functional object, requiring research, thought, modelling, iterative adjustment and redesign.

Road design is a complex task in which judgement and experience play significant roles. Design is the process of selecting and combining appropriate elements that will develop a fit-for-purpose solution. It is an iterative process that requires a designer to exercise their judgement and experience whilst also practically applying accepted technical guidelines and continually evaluating the design to assist in the selection of the appropriate values for the design elements.

In road design, the end result of the design process is presented in drawings and 3D modelling and in specifications to allow the road to be constructed. The philosophy and principles set out in these documents underpin the creation of a successful design. Every road project is a unique undertaking and can never be precisely repeated. There are no ‘off the shelf’ solutions that will fully address all situations encountered, and the rigid and unthinking application of charts, tables and figures is unlikely to lead to a successful design outcome. Good design requires creative input based on experience and a sound understanding of the principles to develop an optimum solution that is within the context of the project and balances often competing and contradictory factors.

Designers choose the features of the road, primary design elements and design dimensions based on technical guides, calculations, and their own experience and judgement. While these may be considered in sequence, consideration of these in isolation from each other is not design. It is essential that designers understand the effects (particularly on safety) of combining limiting values of different design elements under different circumstances.

In situations where road designs are not constrained by topography, natural or man-made features, environmental considerations, or budgetary requirements, the most suitable detailing of a design should not be difficult. However, many situations arise in which constraints apply and, in such cases, the experience and judgement of the designer, together with relevant research and literature, play a significant role in developing the most appropriate outcomes.

All road design is a compromise between the ideal and what is a reasonable solution. It needs to consider the objectives of the project, the objectives of road design and the context of the site. Due to the nature of the design process, the final design solution cannot generally be considered as ‘correct’ or ‘incorrect’ but rather as more or less efficient (in terms of moving traffic), safe (in terms of fatal and serious injury crash reduction), or costly (in terms of construction costs, life-cycle costs and environmental impacts).

3.2 Road Design Principles

A design should be developed with consideration of the Definition of Road Design (Section 3.1) and in accordance with the following principles of road design:

- **Personnel:** A design must be undertaken by a qualified road designer under the supervision of a professional engineer, both with appropriate road design experience in line with the scope of the project. Qualifications must be acceptable to Australian and New Zealand agencies. Designs are normally undertaken by engineering teams with input provided by various other professional disciplines.
- **Project objectives:** A design should meet the objectives of the project while mindful of the objectives for the road link and network. The design team must understand the scope and intention of the project and its relationship to the development of the road network to be able to meet the project objectives.

- **Fit-for-purpose:** A design must be fit-for-purpose, whilst trying to achieve the highest possible standard of design, operational efficiency and safety within the context of the site, the project scope and budget. The design team must understand the purpose and function of the road as well as project scope in order to appropriately apply relevant guidelines and engineering judgement to develop a design solution that is fit-for-purpose. A design should cater for all road-engineering disciplines (geometric design, safety, traffic, drainage, pavements, asset management, etc).
- **Site specifics:** A design must be context-sensitive and consider and incorporate input of all appropriate disciplines and stakeholders to ensure the objectives of road design and a balance of often competing and contradictory factors are achieved. The design team must consider the context of the site as each site is unique. What has worked at one site may not be appropriate for another site. The design team must consider the advice and input of other disciplines and stakeholders.
- **Value engineering:** A design should demonstrate cost-effectiveness through value engineering processes, cost benefit analysis and consideration of whole-of-life costs. Decisions are subject to appropriate review/governance to demonstrate this. Funding for road infrastructure is often limited, therefore the design team must be able to demonstrate value for money by utilising cost-effective treatments, options and solutions.
- **Design element combinations:** A design cannot be considered fit-for-purpose and/or conforming if it simply adopts design minima, particularly in combination, for most or all elements of the design. Most criteria (range/desirable/absolute) have been researched and/or developed in isolation (there may be some implicit relationships) and therefore when used in combination with other elements, while conforming to the published guidelines, may result in a solution that compromises safety and/or operational efficiency.
- **External factors:** The design team must consider all environmental, cultural heritage and social issues and requirements and mitigate any adverse impacts in the most appropriate way possible to satisfy project objectives.
- **Road users:** A design should consider and cater for all road user. It is important that no road user group safety is adversely affected by a proposed design solution.
- **Emerging driver-assist technologies**: The increased potential of vehicles to supplement driver capabilities should be considered. This includes consideration of infrastructure for cooperative intelligent transport systems (C-ITS), either at the time of construction, or for such technologies to be provided in the future.
- **Future planning:** A design should meet current needs whilst also providing for future needs. The design team should ensure that the project accommodates potential future enhancement of the infrastructure (e.g. allowing for future connections within an interchange) or at least does not restrict future enhancement.
- **Innovation:** A design should be developed in accordance with accepted design guidance. Innovative designs may be developed using the foundations provided in accepted design guidance; however, all other road design principles should be maintained. Where accepted design guidance does not provide required warrants and/or dimensional criteria, the design team is responsible for the development of such guidance through a robust engineering and peer review process (to seek acceptance/approval). Any developed guidance must be evidence-based or developed through appropriate, accepted theories and be able to withstand scrutiny by qualified professional civil engineer(s) with appropriate road design experience.
- **Performance:** A design should maintain or improve the performance of an existing road. The improvement of one or more elements should not adversely affect the performance of another. Most road projects now relate to maintenance and enhancement of an existing asset. It is necessary to understand what parts of the design guide are relevant and what parts are not appropriate for the project. A final design solution should not result in the unintentional migration of operational issues to another part of the network.
- **Justification:** Design decisions must be documented including context, basis and rationale. Design solutions and decisions made should be justified and defendable. This principle is crucial for innovative design treatments or solutions (when outside accepted guidance), trials of new treatments and design exceptions. Most road agencies/jurisdictions will have systems/processes in place to specify the documentation of design processes/decisions.

- **Balance:** A design should be able to demonstrate it meets/balances all of the above principles within the limits of the project scope, constraints and is complementary to the network. Design is about achieving an appropriate balance for the project across all aspects and it is important to understand that the balance achieved for one project will likely be different for another.

3.3 Objectives of Road Design

Roads will continue to be an important part of our transport system for the foreseeable future, providing for the safe and efficient movement of people and goods. Road projects are developed to meet increasing travel demand, address crash problems, rehabilitate existing infrastructure, or for a combination of these reasons. A balanced approach towards road planning and design can improve operational efficiency, road safety and public amenity, and minimise the effects of noise, vibration, pollution and visual intrusion on the areas through which a road passes.

Road designs should incorporate the Safe System approach which ensures that the needs of all road users are considered in all aspects of the design process. The objectives of new and existing road projects should be carefully considered to achieve the safest possible road while balancing the level of traffic service provided, whole-of-life costs, flexibility for future upgrading or rehabilitation, and environmental impact. These objectives should address areas including:

- strategic fit with relevant government policies, strategies and plans
- the nature and magnitude of transport demand
- road safety to reduce death and serious injury to all road users
- community views and expectations
- travel times and costs
- freight costs
- public transport provision
- provision for cyclists and pedestrians.

3.4 Geometric Consistency

3.4.1 General

Many characteristics of a road link are already established (e.g. topography, traffic volume and composition), but the geometric form is largely under the control of the designer. The provision of consistent geometric design along roads, particularly roads in rural environments, is an important aspect of road safety. There should certainly be ‘no surprises’ for drivers, such as an isolated sharp curve in a section of road where all other curves have large radii.

Different road classifications are used to indicate the type of service provided. In addition, there are significant variations in topography from area to area and these need to be accommodated in the designs. There should be consistency of design for each road classification, in each terrain type, regardless of location (Transport Association of Canada 1999).

This approach leads to the concept of the ‘self-explaining road’ (Fuller & Santos 2002), that is, a road whose features tell the driver what type of road it is and therefore what can be expected in terms of the elements of the design. This provides a confidence in expectations for the driver, who then operates the vehicle in accordance with those expectations, which in turn are in tune with the nature of the road.

Design consistency can be addressed in three areas:

- cross-section
- operating speed
- driver workload.

It is also important that consistency be achieved in the type of intersections selected and their layout along a route so that driver expectations are met. For example, all other things being equal, the lack of a right-turn lane at one particular intersection when right turn lanes have generally been provided along a route may not be anticipated by some drivers, resulting in rear-end crashes.

3.4.2 Cross-section and Network-wide Design

Roads of the same classification, in similar terrain, should have similar cross-sections. It is particularly important that the cross-section be consistent along any one route, so that drivers are not faced with unexpected changes. Where terrain on a route changes and it is considered necessary to reduce cross-section dimensions for financial or environmental reasons, the safety implications should be assessed.

There will be cases where changes in cross-section dimensions along a route are unavoidable (e.g. where a four-lane divided road becomes a two-lane, two-way road). In these cases, the designer should manage the situation by providing a well-designed transition between the two cross-sections with appropriate tapers and signing.

Austroads have developed a network-wide design approach (refer to Austroads *Guide to Road Design Part 2: Network-wide Design*) which provides further guidance on developing consistent network-wide safety plans to support safer, self-explaining roads for all road users. This methodology uses existing risk assessment tools (including both AusRAP and ANRAM) to pre-calculate a predicted number of FSIs and Star Rating for a cross-section design. It can be used to prepare corridor vision standards that assist in developing design responses at a network level. Decisions made at that level will need to be embedded in project scope requirements to inform subsequent detailed design.

3.4.3 Design Speed

The design of a road must be appropriate for the operating speeds of the vehicles using the road, and the desired or expected speed should be determined in the early stages of the project. The design speed selected for the road environment should consider the principles of the Safe System approach. It should match the road environment to ensure the safety of all road users.

The selected design speed will affect virtually every aspect of the design – horizontal and vertical curvature, sight distances, lane width, superelevation, roadside clearances and barriers. Every effort should be made to design the road to facilitate, and implicitly encourage, a consistent operating speed. Multiple-vehicle crash rates and rates of fatal and serious injuries (FSI) are closely related to the differences in speed between vehicles. These differences can be caused by drivers travelling substantially slower or faster than the average speed of the traffic, or by individual drivers adjusting their speed to negotiate intersections, property entrances and changes in geometry. The greater and more frequent the speed differences, the greater the probability of a higher crash rate and fatal or serious injuries.

Single-vehicle crashes are also affected by speed. Larger reductions in design speed between successive geometric elements of a road produce higher single-vehicle crash and FSI rates. The same outcome results from increased absolute operating speeds on a given road.

Designers can therefore enhance the safety of a road by producing a design that encourages a consistent speed of operation. There are some situations, however, where a change in topography requires substantial reduction in the design speed. In these circumstances, it is preferable for the horizontal curve radii to be gradually reduced through a series of curves with appropriate warning signs in place.

Road networks that do not provide an appropriate road hierarchy may lead to inconsistent speeds of operation. An appropriate mix of higher and lower-order roads in the network, access control and appropriate integration of development can help to resolve these issues.

3.4.4 Driver Workload

Driver workload also has a marked effect on performance at both ends of the spectrum. If driver workload is too low, the driver's attention (i.e. level of alertness) will be too low, with probable loss of vigilance, and the driver may even fall asleep at the wheel. At the other end of the spectrum, if the driver's brain activity level is too high (e.g. stress, information overload, emotional situations), they may compensate by ignoring some relevant information, leading to unsafe operation of the vehicle.

In these circumstances, driver response to unexpected situations may be too slow or inappropriate. It is important that the designer ensure that abrupt increases in driver workload are avoided, as these provide the potential for higher collision rates. These increases can be caused by:

- the nature of the feature (e.g. an intersection or lane drop is more critical than a change in shoulder width)
- limited sight distance to the feature
- dissimilarity of the feature to the previous feature (causing surprise to the driver)
- large percentages of drivers unfamiliar with the road (e.g. a road with a high volume of tourist traffic as opposed to a local road)
- a high demand on the driver's attention after a period of lesser demand (e.g. a sharp curve at the end of a long straight).

Situations where most or all of these factors are encountered simultaneously should be avoided (Transport Association of Canada 1999). Designers' awareness of such factors will enable them to provide the driver with a consistent level of concentration that is neither too low nor too high, but with adequate variation to maintain alertness levels.

3.5 Future Technology Considerations

The road safety benefits of automated, semi-automated, connected and connected and automated vehicles (CAVs) are as yet not fully known and will not be until these vehicles are fully tested on road, in an environment consisting of many similar vehicles. Safety benefits may be influenced by the:

- level and sophistication of these vehicles
- driving performance of these vehicles (as related to reliability and accuracy to behave safely)
- proportion of these vehicles within the vehicle fleet
- interoperability among differently manufactured vehicles and systems
- human interactions with these vehicles.

In the meantime, some manufacturers and researchers have indicated there are likely to be safety benefits of introducing these vehicles into the vehicle fleet. Some of these predictions are based on review of existing crash types and the assumption these would be reduced or eliminated through the introduction of reliable and accurate connected and/or automated vehicles.

There are a number of issues around how these vehicles dynamically 'read' and interact with the road environment that may impact on road design and the safe performance of these vehicles. These issues include, although may not be limited to, the vehicles reading, interpreting and determining how to respond to or act on the following road design elements:

- all types of lane markings
- speed zone signs, speed zone warning signs, variable speed zone signs, and temporary speed zone signs
- curve and other warning signs
- way finding signs

- other road and roadside signage
- all types of vulnerable road user crossings, lanes and facilities
- intersection and junction markings and rules
- entries and exits to highways
- other traffic control measures
- restricted lanes (such as lanes catering for buses, heavy vehicles or vehicles with a greater number of passengers; clearways; etc.)

When developing road design guidelines for these vehicles, consideration will also need to be given to how CAVs will respond to different types and conditions of pavements and in circumstances when these road design features may have degraded.

Some examples of changes to road design guidance for CAVs include:

- lane widths could be reduced or need to be increased depending on context (i.e. if lanes are currently narrow)
- no need for advance speed reduction treatments for rural high-speed roundabouts (such as reverse curves)
- less emphasis on lighting the road for vehicles and more focus on lighting for pedestrians and cyclists.

Despite Australia having unique road rules and road environment, when developing road design guidelines for CAVs, it is essential consideration be given to national and international consistency. This is particularly the case given vehicles are no longer manufactured within Australia and the Australian vehicle market is small compared to some other countries.

Differences between manufacturer specifications for CAVs and interoperability of different CAVs will also need to be considered when developing road design principles for these vehicles and, as mentioned above, will impact on the safety performance of these vehicles.

Refer to Austroads' Technical and Research Reports titled 'Infrastructure Changes to Support Automated Vehicles on Rural and Metropolitan Highways and Freeways' for emerging research in this area (Austroads 2019c, 2019d, 2019e, 2019f and 2019g).

3.6 Performance-based Design

Ultimately, the key function of a road is to cater for the performance characteristics of its users (motorised or otherwise). It is recognised that in some circumstances, site or project-specific constraints – including financial – may prohibit the use of one or more design parameters that would typically be preferred.

Performance-based design anticipates the performance effects of design decisions on aspects that include:

- traffic operational efficiency
- existing and expected future crash frequency and severity
- construction cost
- future maintenance cost
- functional classification
- use by each transportation mode
- accessibility for persons with disabilities
- available right-of-way

- existing and potential future development
- operational flexibility during future incidents and maintenance activities
- stakeholder input
- community impacts and quality of life
- historical structures
- impacts on the natural environment.

Performance-based analysis provides a key basis for the exercise of design flexibility.

Flexible design emphasises the role of the planner and designer in determining appropriate design dimensions based on project-specific conditions and existing and future roadway performance more than on meeting specific nominal design criteria. In the past, designers sought to assure good traffic operational and safety performance for the design of specific projects primarily by meeting the dimensional design criteria in the road design guides. This approach was appropriate in the past because the relationship between design dimensions and future performance was poorly understood. Recent research has improved our knowledge of the relationship between geometric design features and traffic operations for all modes of transportation and has developed new knowledge about the relationship of geometric design features to crash frequency and severity (AASHTO 2018).

In these circumstances, deviations from typical best practice may be acceptable if there is sufficient evidence to demonstrate that performance for all road users will achieve an acceptable standard – particularly with regards to safety.

The concept of performance-based design is an extension of many of the principles of the Extended Design Domain (Section 4.4.2) seeking a balance of the performance measures.

3.7 Community Expectations

The involvement of stakeholders throughout the planning process helps to ensure that all issues and needs are identified and considered, and that outcomes have a high degree of support and ownership. Public consultation is therefore an essential part of all road planning and design activities. The importance of the Safe System approach to road design should be communicated to the community to gain its support and acceptance.

Community expectations may be general or specific in nature. The expectations may relate to economic, social, safety, traffic management or environmental aspects. There may be concern about the visual impact of the project on the landscape or aspects such as traffic noise and air pollution. Design aids to provide three-dimensional impressions and models of the project may assist in providing the community with a picture of the project or project options. Specialist consultant reports describing important archaeological, heritage and natural environment features in the corridor can assist in the resolution of these issues in relation to design options.

Particular stakeholder groups may have specific concerns about the performance of an existing road and the ability of a proposed project to improve the performance. For example, concern may be expressed by:

- motoring associations with respect to travel time costs or significant delays
- freight operator associations about the cost of moving freight
- public transport operators and users regarding schedules and reliability of services.

For projects where the needs of special road user groups have to be accommodated at the expense of other users, community expectation must be carefully managed through the consultation process. Examples include the reallocation of general traffic lanes for use as transit lanes, bus lanes or bicycle lanes, or the provision of tram stops that provide equitable access to public transport for disabled persons.

4. Road Design Application

4.1 Road Characteristics and Use

4.1.1 Functional Classification and Use

The standards adopted for road projects are usually influenced by the functional classification of the road. For example, roads of higher classification have a major role in the transportation task and therefore require a higher standard of design. Roads fall into a hierarchy of functional classes ranging from major arterial roads to local access roads.

The recent developments in policy and planning initiatives giving greater recognition to more sustainable forms of transport in urban areas (Section 2.3.3) have led to consideration of a road user hierarchy in addition to the traditional road hierarchy. The road user hierarchy indicates the relative priorities to be accorded to road user categories in the operations of the road network. In accordance with this, pedestrian activity is often identified for priority consideration on some sections. This needs to be integrated and balanced with priorities arising from the prevailing functional road classifications.

Functional classes are not always clear-cut since almost all roads have some degree of local importance.

Rural roads of higher functional class generally cater for a higher (though normally still modest) proportion of longer-length journeys generally at higher speeds, and it may be appropriate to select higher design standards for such roads so that the quality of service is more appropriate to the longer trip duration. However, designers must beware of placing too much importance on functional class alone where traffic volumes are low. Austroads has defined a system of functional classification for rural roads (Table 4.1).

In rural areas, the Class 1 and 2 roads in Table 4.1 are generally freeways or major highways that have a high standard for two-way two-lane roads. They are usually roads of national or state importance in terms of communication and the economy. Class 3 roads would generally be main roads of a satisfactory but lesser standard than the Class 1 and 2 roads.

Austroads has also adopted a rural route numbering hierarchy to assist road user guidance. This hierarchy identifies arterial routes as M, A, B or C routes and, similar to the classification in Table 4.1, is also related to the route characteristics. This is discussed in more detail in the Austroads (2016b and 2019c).

The functional classification of urban roads (refer to Table 4.2) is usually less clear than that of rural roads, as urban roads generally are flanked by dense development that requires frequent access at the boundary of the road. Historical requirements for kerbside parking and other uses (e.g. public transport routes or bicycle routes) further complicate functional definitions.

Most urban arterial roads continue to function as major through traffic routes, but the management of these roads often requires space to be dedicated to public transport or bicycle use in preference, or in addition to private car travel. There is also a trend on inner suburban roads for speed limits to be lowered to address pedestrian safety issues while sections of inner-city streets (formerly through arterial routes) are sometimes converted to pedestrian areas or shared zones. This is discussed in more detail in the *Guide to Traffic Management*. Consequently, the function of particular sections of road may change over time in accordance with community values.

Table 4.1: Austroads functional classification of rural roads

Road class	Route classification	Route characteristics
Arterial roads		
Class 1	M	Those roads, which form the principal avenues for communications between major regions, including direct connections between capital cities.
Class 2	A	Those roads, not being Class 1, whose main function is to form the principal avenue of communication for movements between: • a capital city and adjoining states and their capital cities; or • a capital city and key towns; or • key towns.
Class 3	B or C	Those roads, not being Class 1 or 2, whose main function is to form an avenue of communication for movements: • between important centres and the Class 1 and Class 2 roads and/or key towns; or • between important centres; or • of an arterial nature within a town in a rural area.
Local roads		
Class 4		Those roads, not being Class 1, 2 or 3, whose main function is to provide access to abutting property (including property within a town in a rural area).
Class 5		Those roads, which provide almost exclusively for one activity or function, which cannot be assigned to Classes 1 to 4.

Table 4.2: Urban road functional classification

Type of road	Function
Controlled access highways (motorways or freeways)	Motorways and freeways have an exclusive function to carry traffic within cities and to ensure the continuity of the national or regional primary road system. As they are designed to accommodate through traffic, they do not offer pedestrian or frontage access.
Urban arterial roads	Urban arterial roads have a predominant function to carry traffic but also serve other functions. They form the primary road network and link main districts of the urban area. Arterial roads that perform a secondary function are sometimes referred to as sub-arterial roads.
Urban collector/distributor roads	These are local streets that have a greater role than others in connecting contained urban areas (e.g. residential areas, activity areas) to the arterial road system. Generally, consideration of environment and local life predominate, and improved amenity is encouraged over the use of vehicles on these roads.
Urban local roads	These are roads intended exclusively for access with no through traffic function.

4.1.2 Factors that Influence Design Standards

The road traffic system comprises three elements that combine to define how a road or a design will perform, particularly in terms of safety – the vehicle, the human input and the road.

The vehicle

In relation to their mode of transport, road users can be divided into three categories:

- users of motorised vehicles such as trucks, buses, cars and motorcycles
- users of non-motorised or low-powered vehicles such as bicycles and powered wheelchairs
- users without vehicles, that is, pedestrians.

Users in the first category influence road design primarily through the characteristics of the vehicles they operate. For convenience, these are often represented by the characteristics of design vehicles. The physical and operating characteristics of vehicles using major roads are important factors in geometric design. The design vehicle is a hypothetical vehicle whose dimensions and operating characteristics are used to establish lane width, intersection layout and road geometry. For most design situations on arterial roads the car is used as the design vehicle for horizontal and vertical geometry, while a prime mover with semi-trailer is used as the design vehicle for cross-section elements and intersections. In some cases, it may be appropriate to consider expected bicycle usage. However, it is important to ensure that roads are designed to cater for vehicles that commonly use them and the most appropriate Austroads or Land Transport New Zealand standard vehicle should be adopted.

The geometric design should be checked for the largest design vehicle expected to use the road, using the *Austroads Design Vehicles and Turning Path Templates Guide* (Austroads 2013a). See also *On road tracking curves for heavy vehicles* (NZTA 2007).

When designing arterial road intersections it is common practice to design for a particular vehicle and then to check that a selected larger vehicle can negotiate the intersection turning from lanes other than the preferred turning lane, or by mounting specially paved areas if necessary (Austroads 2017a). The check vehicle should be chosen according to its potential to use the facility, using a risk management approach. Local knowledge of current or proposed developments or industrial activities in an area may assist the choice of the most appropriate check vehicle.

Another heavy vehicle characteristic that relates to geometric design is the height of van-type semi-trailers in terms of stability on tight turns at intersections and also in relation to overhang created on existing roads that have excessive crossfall in the left traffic lane (resulting in reduced clearances to utility poles, trees and road furniture).

Heavy vehicle dynamics can also influence horizontal alignment design (curve size, superelevation and transitions), sight distance provision, grading, traffic signal design, railway level crossings and auxiliary lane provision.

On-road public transport utilises motorised vehicles that may place special requirements on road design. As is the case for trucks, on-road public transport vehicles may be large enough for their turning and tracking characteristics to place particular constraints on design dimensions. In addition, however, the need for frequent loading and unloading of passengers, the possible provision of priority for public transport at intersections or mid-block locations, and the potential for transitions of trams and light rail between on-road and exclusive right-of-way operations are examples of public transport characteristics that directly affect design decisions.

Road users in the second and third categories – users of non-motorised or low-powered vehicles, and pedestrians – influence road design in many ways, but primarily through their two major distinguishing characteristics:

- their vulnerability relative to motorised traffic
- their lower speeds of operation compared to motorised traffic.

Because of these characteristics, it may be desirable to provide separate facilities for these users, in the form of bicycle, pedestrian or shared paths either on the roadside or in their own rights-of-way. Where such facilities are not provided for bicycles and they must operate on the road carriageway, the designer should consider the provision of a bicycle lane, which affords a degree of protection to cyclists and reduces the effects of their speed differential relative to adjacent traffic. The treatment of such lanes at and near intersections requires particular attention from designers.

Cyclists, pedestrians and other road users in the second and third categories also require designers to give specific consideration to their needs in crossing motorised traffic flows, at intersections or at mid-block locations.

Human factors

Road user behaviour is central to almost all decisions required in the design of roads. The efficient and safe operation of the road system depends greatly on the performance of drivers of vehicles, riders of motorcycles or bicycles, and pedestrians. Common aspects of road user behaviour provide the basis for many design parameters such as speed selection, curve design, and operation of intersections and crossings. An understanding of road user behaviour may assist designers to better understand the basis of standards and guides and hence to produce appropriate designs.

Driving or riding a vehicle has three essential tasks (AASHTO 2018):

- navigation – trip planning and route following
- guidance – following the road and maintaining a safe path in response to traffic conditions
- control – steering and speed control.

These tasks require a vehicle operator to receive inputs (most of which are visual), process them, make predictions about alternative actions and decide which is the most appropriate, execute the actions, and observe their effects through the reception and processing of new information (Lay 1985).

Many geometric design standards are influenced by the sensory ability of vehicle operators and pedestrians, in particular, vision and (especially for cyclists and pedestrians) hearing. Vibration and hearing may be important for some types of traffic control devices (e.g. audio-tactile edge lines, rumble strips and level-crossing bells). Visual acuity, colour sensitivity, and peripheral vision are all important to the driving or riding task. Driver visual sensitivity deteriorates in poor light conditions, with aging and with alcohol consumption. Visual recognition takes a finite time and the total response time of drivers has a significant effect on a range of design elements, including sight distance requirements and sign face design.

Physical abilities (other than vision) that are relevant to the driving/riding task relate to vehicle control, tracking, curve negotiation, and reaction times. Vehicle operators' physical attributes influence standards and guides relating to elements such as deceleration lane lengths, curvature, lane widths (ability to track) and sight distance (reaction time, eye height).

The behaviour of cyclists and pedestrians, as road users, is potentially subject to greater variation than that of motor vehicle drivers because riding or walking does not require a licence and there are thus no formal lower or upper limits placed on the age or the physical abilities of these road users. Children may be particularly vulnerable as cyclists or pedestrians, having wider variations in cycling stability, cycling or walking speeds and general road sense than is the case for the bulk of adult riders or pedestrians. Equally, the elderly may suffer deterioration in vision, hearing, reaction times and/or walking capabilities that need to be taken into account in road design.

Provision for those with physical disabilities, who most often are operating as pedestrians or wheelchair users, also places particular requirements on road design, for example, in relation to footpaths or shared paths, crossing locations and design, and needs for non-visual information transfer.

Road factors

Principles that lead to a safe road environment are described in Section 3.2. Horizontal and vertical alignment, cross-section, surface conditions and roadside design all impact on operating speeds and safety, and the extent of those impacts must be estimated.

The effect of grade on vehicle speeds is a typical example of an impact of a design decision on the performance of the road-traffic system, the following being aspects of that impact that may be taken into consideration:

- The operating speed of cars may be reduced on upgrades longer than 200 m.
- The operating speed of laden trucks will be significantly reduced on long up-grades.

- Cars will generally travel at the operating speed on steep down-grades; however, some increase could be expected toward the end of a down-grade.
- The ultimate capacity of the road corridor may be reduced on long or steep up-grades.
- Trucks may be required to significantly reduce their speed prior to steep down-grades.

Corrections for grade should be considered for each element of the road (Austroads 2013a). This is particularly necessary when there is a significant change in topography. Refer to AS 1742.9 for further information on treatments to alert drivers of an approaching steep grade.

Speed estimates used in design generally relate to typical road cross-sections (i.e. those with traffic lanes wider than 3 m). On roads with lanes narrower than 3 m, the speed estimates may be reduced to account for narrower lanes (Austroads 2013a).

Average pavement conditions are assumed for the speed estimates used in road design. On roads where a poor or broken surface or a gravel surface is likely to prevail it may be appropriate to assume reduced speeds.

4.1.3 Speed Parameters

Safe speed is central to the severity outcome of any crash. Speed is also an important element in road design, governing a number of principal design parameters, including:

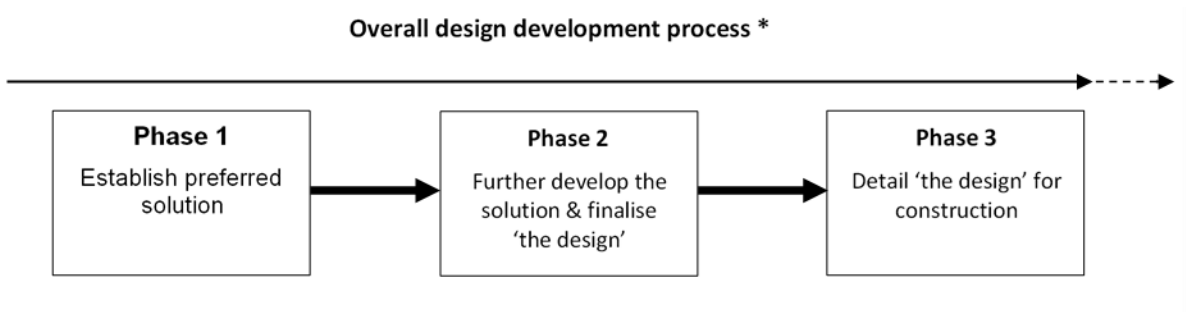
- stopping distance
- sight distance
- horizontal curve radius
- traffic lane width
- pavement superelevation.

As these parameters are related directly to the speed of traffic on the road, one of the first requirements in design is to establish the appropriate speed or speeds to use for design. Austroads (2013a) discusses in detail how this is achieved for both rural and urban roads.

4.2 Phases of Design

The design of major road infrastructure is essentially delivered in three phases as shown in Figure 4.1. Some phases may not be required, depending on road agency requirements. Often, the first two phases are not undertaken for minor works. Whilst the representation of the overall design process is shown to be 'linear', it should be noted that design is iterative and that changes, particularly as more detailed information becomes available, may cause earlier phases to be revisited.

Figure 4.1: Phases in the design process



** Design changes during construction.*

It should be noted that designers are increasingly being required to provide more input into the planning task for the transport network. Part 2 of the GRD will focus on the role a project may play in the greater network and how project outcomes are influenced by network design activities, hence preliminary work before designers even begin Phase 1 may include:

- Exploring the strategic fit of the project in the transport network
- Defining the project definition through gap analysis and problem validation
- Explore the high-level feasibility of transport options

4.2.1 Phase 1 – Establish the Preferred Solution

The establishment of a preferred solution comprises the following steps:

- Review the design brief and clarify the aims of the project.
- Define the study area.
- Identify options within that area.
- Undertake initial studies.
- Develop the concept design for each option.
- Analyse the options.
- Recommend a preferred option.

While the roles of the authorities will depend on the road agency, these steps are generally held to be within the realm of the project manager, and the level of design involvement in each step will depend on the authorities, the nature of the particular project and relationships. Again, it should be noted that the process is iterative and issues arising in later steps may cause a re-evaluation of earlier ones including the definition of the study area.

Review the design brief and clarify the aims of the project

The designer should review the design brief in accordance with Appendix A.1.

Before undertaking any work, it is essential to clarify the aims of the project with the client and project manager. This will ensure that there is a common understanding of the desired outcome, the timeframe and the financial constraints before any work begins. This step should also establish whether there is information available from previous planning and/or earlier designs, plus any known constraints (financial, physical, environmental, legislative and social). Failure to establish these aims initially may lead to subsequent frustration, delay, ill-feeling, rework and additional and thus unnecessary cost.

All inputs should be reviewed for adequacy and the designer should identify whether any additional inputs are required. Generally, preliminary investigations will be required.

Confirm that the typical cross-section is applicable.

Define the study area

This step is critical because it sets the boundaries outside of which options will not generally be considered. The boundaries are not just planar but should be three dimensional and include setting any height and depth restrictions.

For the designer, many of these inputs will be determined by others and will be considered by the designer as inputs to the design process and dealt with under the principles outlined in Appendix A.1. If not, there may be some other imposed constraint, such as a coastline, that will limit the range of options and hence help define the study area.

The project brief should identify the study area and its constraints.

Major issues typically pre-determined for the designer are whether the solution must be restricted to the existing road corridor and the nature of the typical cross-section (i.e. whether the cross-section has been established as part of broader network corridor planning).

Identifying options within that area

Ideally, the aim is to identify all plausible solutions. However, in some circumstances there are an 'infinite' number of solutions; this is generally taken to require a sufficiently broad enough range of options to allow for sensitivity to be assessed.

Typically, a project team will be utilised to identify the broad options and the designer will then provide sufficient detail to establish the advantages and disadvantages of each.

Undertake initial studies

To identify the broad strategic options, a number of preliminary investigations may need to be undertaken. The degree to which these investigations are undertaken will depend on an assessment of risk and the level of current information and understanding available. Options can be ruled out if a 'fatal flaw' factor can be identified.

Investigations by, or on behalf of, the project team might be carried out in the following areas of impact:

- community interests (both local and impacted) and those of other stakeholders (e.g. other government agencies, industry groups)
- environment e.g. habitat (flora/fauna), heritage etc.
- hydrology e.g. flooding, outfalls (Austroads 2013b)
- geotechnical (Appendix B)
- traffic analysis, including major and minor road connections (Austroads 2020b)
- land acquisition and property access impacts
- pedestrian and cyclist provisions (Austroads 2016a and 2017b)
- utility impacts (Austroads 2020a)
- any other constraints/issues and opportunities specific to the project.

Develop the concept design for each option

Develop the concept design for each solution option to the extent necessary to allow the comparison of options. While this will again typically be done by a project team, the majority of the development is generally done by the designer.

This should be done in accordance with the principles outlined in Appendix A.2.

Analyse the options

This should be done in accordance with road agency requirements but will typically involve the use of a decision-making aid, for example, a value management workshop. The output from this will be an options comparison report typically detailing the road agency requirements and reporting against them for each option.

Recommend a preferred option

Depending on the jurisdictional requirements, the recommendation of a preferred option may require additional steps including outlining some of the valid options from which the preferred solution was selected. Ultimately the recommended solution must be accepted/approved by the client before subsequent work is undertaken.

4.2.2 Phase 2 – Further Develop the Solution

Having decided on a preferred option, the next phase in the design development process requires the further development of that preferred solution to give sufficient confidence that it can be built and meet all requirements. In some jurisdictions it may also form the basis for the formal environment assessment.

The design should now be developed in sufficient detail to allow:

- individual elements to be recognised and analysed
- the relationship and interaction of those elements to be clear
- options for change to elements within the design to be identified.

It should comprise the following steps:

- Review the design brief.
- Review the preferred option (if Phase 1 output has been provided).
- Undertake supplementary studies.
- Develop the design.

Review the design brief

The designer should review the design brief in accordance with Appendix A.1.

Note that there may be a significant time lapse between Phase 1 and Phase 2, and it is therefore essential that the design intent is clearly transferred between phases and well-documented outputs including the design report will assist with this. It is good practice for the designer to reaffirm the previous recommendations/decisions with the client and project manager (who may be new to the project) before proceeding with further development as described in this phase.

Review all inputs for adequacy and identify whether any additional inputs are required. Generally, more detailed investigations will be required.

Confirm that the typical cross-section is still applicable and is appropriate. As the overall decision process is ‘linear’, it should be noted that changes, particularly to the scope, may cause the previous phase to be revisited. It may be difficult to change once this phase is completed.

Review the preferred option design

The designer should also comprehend the requirements, issues and other information from Phase 1. This is especially important where a new team is engaged to deliver this next phase of the design. It is essential that further development/rework of the design is not undertaken without first understanding the context of the design from an earlier phase.

Then the preferred option should be reviewed against the project and design requirements.

Undertake supplementary studies

The preliminary investigations undertaken for Phase 1 of the design process will most likely not be adequate for the further development of the preferred option. The degree to which these supplementary investigations are undertaken will again depend on an assessment of risk and the level of current information and understanding available. The results should provide enough information to allow a sufficiently high level of confidence that the project can be built and that it will meet the design requirements.

Develop the design

The design should be developed in accordance with the requirements of Appendix A.2.

This step in the further development of the design completes this phase and should provide sufficiently detailed design documentation (including plans and design report) to allow for:

- compliance with applicable statutory and regulatory requirements to be confirmed
- any environmental assessments to be undertaken
- sufficient guidance to be provided to allow for the next phase, that of detailed design, to be undertaken with minimum risk.

Again, it should be noted that the process is iterative and issues arising in the development of the design for the preferred option may cause a refinement of the previously approved design including adjustments to line and level.

A primary output is a set of coordinated alignments that satisfy geometric design standards.

The aim is to not only produce a conforming design but one that results in the best design solution for the site-specific situation.

4.2.3 Phase 3 – Detailed Design: The Design for Construction

Having developed the preferred solution, the last phase in the design development requires the production of sufficient detail to allow the work to be constructed and meet all requirements.

A detailed design should be suitable for inviting tenders and should allow for all aspects of the construction to be completed.

It may comprise the following steps:

- Review the design brief.
- Review the developed option.
- Undertake supplementary studies.
- Develop the design.
- Review the design during construction.
- Prepare the construction record.

Review the design brief

The designer should review the design brief in accordance with Appendix A.1.

Review all inputs for adequacy and identify whether any additional inputs are required. More detailed investigations may be required for individual elements.

Whilst confirming that the typical cross-section is still applicable and is appropriate, this should not change from that used in Phase 2, because it is usually difficult to change at this stage due to impacts on broader network decision making.

Review the developed option

The designer should also comprehend the requirements, issues and other information from Phase 2. This is especially important where a new team is engaged to deliver this next phase of the design.

Then the preferred option should be reviewed against the design requirements, especially the requirements arising from any consultation or formal assessment of the Phase 2 output and in this regard, the environmental assessment may be critical.

Undertake supplementary studies

The more detailed investigations undertaken for Phase 2 of the design process may still not be adequate for the further development of the preferred option, especially the results of any consultations and assessments undertaken on the Phase 2 output. The degree to which these supplementary investigations are undertaken will again depend on an assessment of risk, particularly construction cost, and the level of current information and understanding available.

They should provide enough information to allow a sufficiently high level of confidence that the design can be built and that it will meet the design requirements.

Develop the design

The design should be developed in accordance with the requirements of Appendix A.2.

As noted above, the purpose of this phase of the design is to provide sufficient detail to allow for tendering and construction purposes and will, amongst other outputs, include:

- finalised design documentation, whether electronic or hard copy
- a schedule of all quantities
- appropriate inputs to the construction specifications
- confirmation of compliance with applicable statutory and regulatory requirements.

Review the design during construction

Remedial design or further design development during the construction phase may be necessary for a number of reasons including:

- tender reference design not being a fully developed detail design
- alternatives put forward during the tender process and accepted
- non-conformance during construction
- accepted changes whether initiated by the construction contractor or otherwise
- previously unidentified inputs, for example, utilities
- an error in the design.

The design should be changed in accordance with Appendix A.3.6.

Prepare the construction record

The intent is to provide a record of the details of the actual construction. It should be noted that the terminology differs according to jurisdiction but all give the same indication. The most common descriptors are:

- work as built
- work as executed
- work as constructed.

The documented record generally takes the form of a marked-up set of plans and design reporting, driven by the various state and territory legislative requirements for record keeping. It is expected that, over time, the various statutory requirements may be changed to allow for the use of electronic models as the record. The emerging BIM system requires the as-built 3D electronic models (digital engineering) to be stored and made readily accessible.

4.3 Context-sensitive Design

A road is but one element of a transport system, which operates in the natural and built environment to meet a range of expectations of the users and the broader community. The design cannot be carried out in isolation but must be sensitive to the context in which the road will operate.

> Context-sensitive design (CSD) is an approach that provides the flexibility to encourage independent designs tailored to particular situations. CSD seeks to produce a design that combines good engineering practice in harmony with the natural and built environment and meets the required constraints and parameters for the project.

A national conference sponsored by the Maryland State Highway Administration and FHWA in 1998 produced a definition of context-sensitive design that has been adopted by many (AASHTO 2004):

> *Context-sensitive design asks questions about the need and purpose of the transportation project, and then equally addresses safety, mobility and the preservation of scenic, aesthetic, historic, environmental, and other community values. Context-sensitive design involves a collaborative, interdisciplinary approach in which citizens are part of the design team.*

The challenge is to develop a design solution that takes account of the competing alternatives and the trade-offs that might be needed. Factors that should be considered in these trade-offs include:

- mobility and reliability
- environmental impacts
- loss of consistency of design (a safety issue)
- reduction in the life of the infrastructure
- capital costs
- whole-of-life costs (e.g. maintenance costs, vehicle operating costs)
- aesthetics.

The end product must be internally consistent, consistent with the expectations for the type of road, and compatible with road design principles presented in this guide and other relevant documents. The reasons for adopting any particular design criteria and/or parameters must be robust, defensible, fully documented and in keeping with the Safe System approach as outlined in Section 2.2.

The principles of context-sensitive design have been outlined by the US Federal Highway Administration (FHWA) and are addressed in FHWA (2012). FHWA identify the following qualities of excellence in transportation design:

- The project satisfies the purpose and needs as agreed to by a full range of stakeholders. This agreement is forged in the earliest phase of the project and amended as warranted as the project develops.
- The project is a safe facility for both the user and the community.
- The project is in harmony with the community, and it preserves environmental, scenic, aesthetic, historic, and natural resource values of the area, i.e. exhibits context-sensitive design.
- The project exceeds the expectations of both designers and stakeholders and achieves a level of excellence in people's minds.
- The project involves efficient and effective use of the resources (time, budget, community) of all involved parties.
- The project is designed and built with minimal disruption to the community.
- The project is seen as having added lasting value to the community.

The characteristics of the process contributing to excellence include:

- Communication with all stakeholders is open, honest, early, and continuous.
- A multidisciplinary team is established early, with disciplines based on the needs of the specific project, and with the inclusion of the public.
- A full range of stakeholders is involved with transportation officials in the scoping phase. The purposes of the project are clearly defined, and consensus on the scope is forged before proceeding.
- The highway development process is tailored to meet the circumstances. This process should examine multiple alternatives that will result in a consensus of approach methods.
- A commitment to the process from top agency officials and local leaders is secured.
- The public involvement process, which includes informal meetings, is tailored to the project.
- The landscape, the community, and valued resources are understood before engineering design is started.
- A full range of tools for communication about project alternatives is used (e.g. visualisation).

4.4 The Design Domain

A design domain can be thought of as a range of values that a design parameter might take. It is a range of design parameters that can be justified in an engineering sense (based on test data, sound reasoning, etc.) and therefore can have a reasonable level of defence if questioned.

The design domain has always existed for road infrastructure design. Although it may not have been explicitly described, it has been implicit in publications such as the Guide to Road Design and Guide to Traffic Management series.

It consists of the normal design domain (NDD) and the extended design domain (EDD).

4.4.1 Normal Design Domain

The design domain for a new road is referred to as the 'normal design domain' or NDD. The extent of the normal design domain defines the normal limits for the values of parameters that have traditionally been selected for new roads.

Often there is a NDD range of values that is specified in the guide for each design element. This range of values gives designers flexibility to;

- Address the network and project purpose and need (objectives of the network/project)
- Design that responds to the specific project and corridor context
- Explore combinations of values for different design elements to address the two points above

For any design parameter there is a practical upper limit beyond which incremental benefit diminishes. The practical upper limit for a new road shown in Figure 4.3 corresponds to the maximum value for any particular parameter (where applicable) in the *Guide to Road Design*. For example, the practical upper limit of lane width for a rural road is given as 3.7 m, exclusive of curve widening (Austroads 2016a). In some cases, an increase in a parameter above a particular value may result in a disbenefit in terms of road safety (e.g. shoulder width above 3.0 m).

The practical lower limit for a new road shown in Figure 4.3 corresponds to the minimum values given for any particular parameter in the Guide to Road Design. For example, the practical lower limit of lane width for a rural road is 3.5 m (Austroads 2016a). As a general rule, values below the practical lower limit should not be chosen for a new road unless constraints apply and they can be justified.

The extent of the normal design domain within the various manuals and guidelines is usually based on the experience and judgement of practitioners, even where the relationship with safety has been identified by research. This can vary over time, depending on current subjective thinking and on changes in road/traffic characteristics. For example, vehicle fleet changes have led to a decrease in the design value for driver eye height and a consequent increase in the minimum length of crest vertical curves.

Throughout the Guide to Road Design, the NDD is described within the body of each part and values for the EDD, where appropriate, are introduced within an Appendix or Commentary to the part.

4.4.2 Extended Design Domain

As shown in Figure 4.3, the EDD is a range of values below the lower bound of the NDD. Therefore, EDD is a range of design values below the minimum values traditionally specified for new roads in road design guidelines. EDD values are generally only used for existing roads in constrained situations and may include:

- those established within the Austroads *Guide to Road Design*
- those established by a road agency (client) for use within its own jurisdiction.

EDD values are developed based on the following principles:

- an appropriate risk-based process
- a sound technical and engineering basis
- engineering and professional judgement
- an existing satisfactory safety performance.

The EDD concept uses design values smaller than the practical lower limit in certain circumstances, where they can be justified and defended on engineering grounds and operating experience. Use of values within the EDD should be supported by a documented risk assessment that:

- justifies and recommends the values to be adopted for various design parameters
- demonstrates that adoption of lower values is in the overall community interest with respect to investment strategies, road safety strategies, and other strategies that relate to roads and road networks
- verifies that responsibility for the use of values within the EDD is taken corporately by the relevant road agency and is not placed on an individual designer.

Most road design guidelines are based on theoretical safety models because of the inherent difficulty in determining standards based on objective safety evidence. The lower-bound values used in the EDD approach recognise that models developed for the design of new roads can produce values that are conservative for some situations. The concept of EDD uses less conservative values for some input parameters on the basis that they can be supported by comprehensive engineering test data and deliver reasonable outcomes if applied in an appropriate context.

The use of EDD may be limited to particular parameters (e.g. sight distance) where research has demonstrated that the adoption of EDD will not result in significantly higher crash rates. While the use of design values from within the EDD may not be preferred, it may be necessary in certain circumstances, usually for existing roads in constrained situations. Improving existing roads, particularly the geometry of existing roads, is relatively expensive. Furthermore, the cost differential between upgrading a road to a level within the normal design domain compared to a level within the EDD is likely to be high in these cases. In contrast, the relative cost differential between providing a road that conforms to the normal design domain, compared to the EDD, is likely to be relatively less for a new road (i.e. at a greenfield site).

Table 4.3 lists situations where the use of normal design domain, extended design domain and design exceptions may be applicable.

Table 4.3: Typical use of normal and extended design domain and design exceptions

Normal design domain	Extended design domain	Design exceptions (see 4.5)
• New construction (greenfield sites) • Significant lengths of reconstruction of existing roads • New carriageway of a duplication	• Assessment of existing roads • Improving the standard of existing roads in constrained situations • New carriageway of a duplication in constrained situations • Temporary situations (e.g. projects where it is known that imminent development will cause a permanent reduction in the operating speed)	• Existing roads with significant restrictions due to existing infrastructure • Challenging terrain • Reduce or eliminate impacts on sites of cultural significance or heritage • Reduce or eliminate environmental impacts • Community expectations • Temporary roadworks

Designers should be aware that simply adopting minimum values (including EDD values) for several design elements simultaneously may produce an unsafe and/or unsatisfactory result. For example, combining a minimum radius horizontal curve with a minimum radius vertical curve and a minimum formation width may be a hazard to road users. Where a minimum is adopted for one geometric element, it is desirable to adopt a standard that is above the minimum for other elements (e.g. increase the pavement width to allow vehicles to manoeuvre on an absolute minimum radius vertical curve). This principle is particularly relevant when applying the EDD concept.

Values for EDD for particular parameters may be established by the relevant road agency using the EDD principles described above. Subject to agreement with other road agencies, it is ultimately desirable that such criteria be included in the Guide to Road Design, in the same manner that NDD criteria are being included.

A value within the EDD can only be used with the explicit corporate approval of the relevant road agency.

4.4.3 Application of the Design Domains

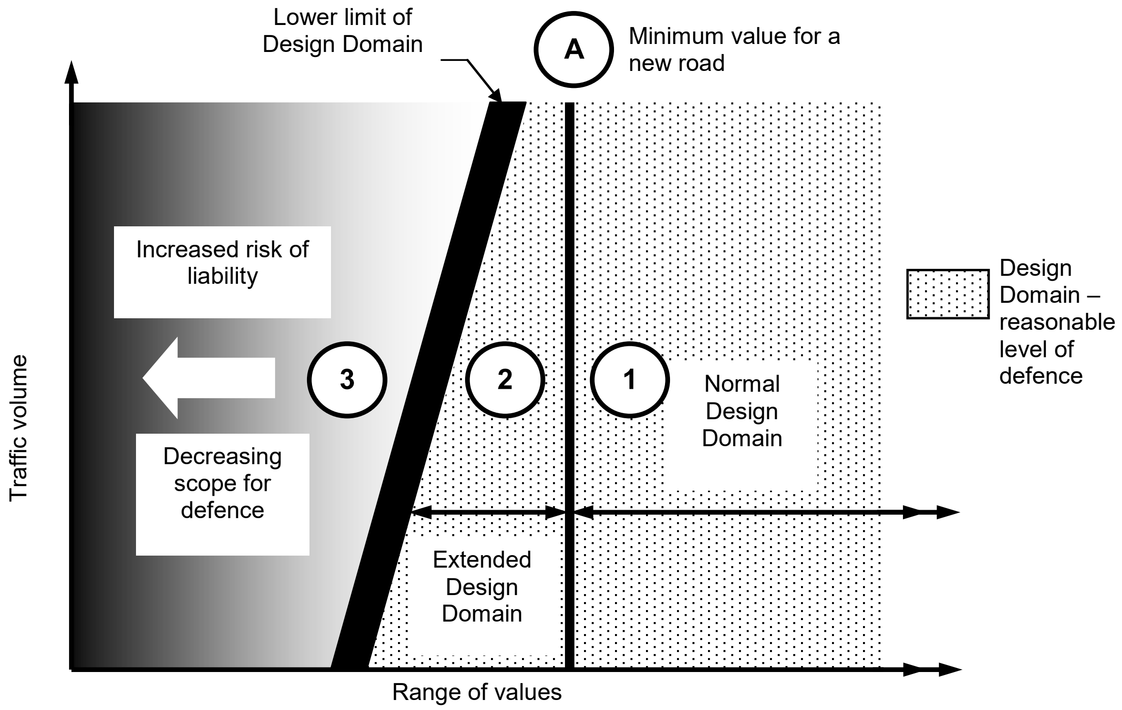
Figure 4.2 is a conceptual diagram showing the NDD, the EDD, and how the level of defence against litigation may change for a given geometric parameter. Defence against litigation needs to be considered when adopting particular values of a geometric parameter for restoration of an existing road.

In the past, the lower bound of the design domain has been seen as the minimum value/s contained in publications such as the Guide to Road Design, irrespective of the application (i.e. to a new greenfield road or to an existing road). This is represented by Line A in Figure 4.2. The vertical line denotes a geometric parameter whose value is not influenced by traffic volume (e.g. crest curve radius).

EDD extends the lower bound of the design domain that is used for a new road, based on what can be justified and defended, on engineering grounds, in certain circumstances (Area 2 in Figure 4.2). However, a value within the EDD can be used only with the explicit, corporate approval of the relevant road agency, supported by a documented risk assessment that fully justifies the use of that value.

The design domain in Figure 4.2 (Area 1 plus Area 2) incorporates the NDD and the EDD. The lower regions of the design domain represent conditions that would generally be considered less safe, less efficient and usually less expensive than those in the upper regions, however caution should be applied to avoid aiming for minimum criteria.

Figure 4.2: Conceptual diagram



Source: Queensland Department of Transport and Main Roads (2013).

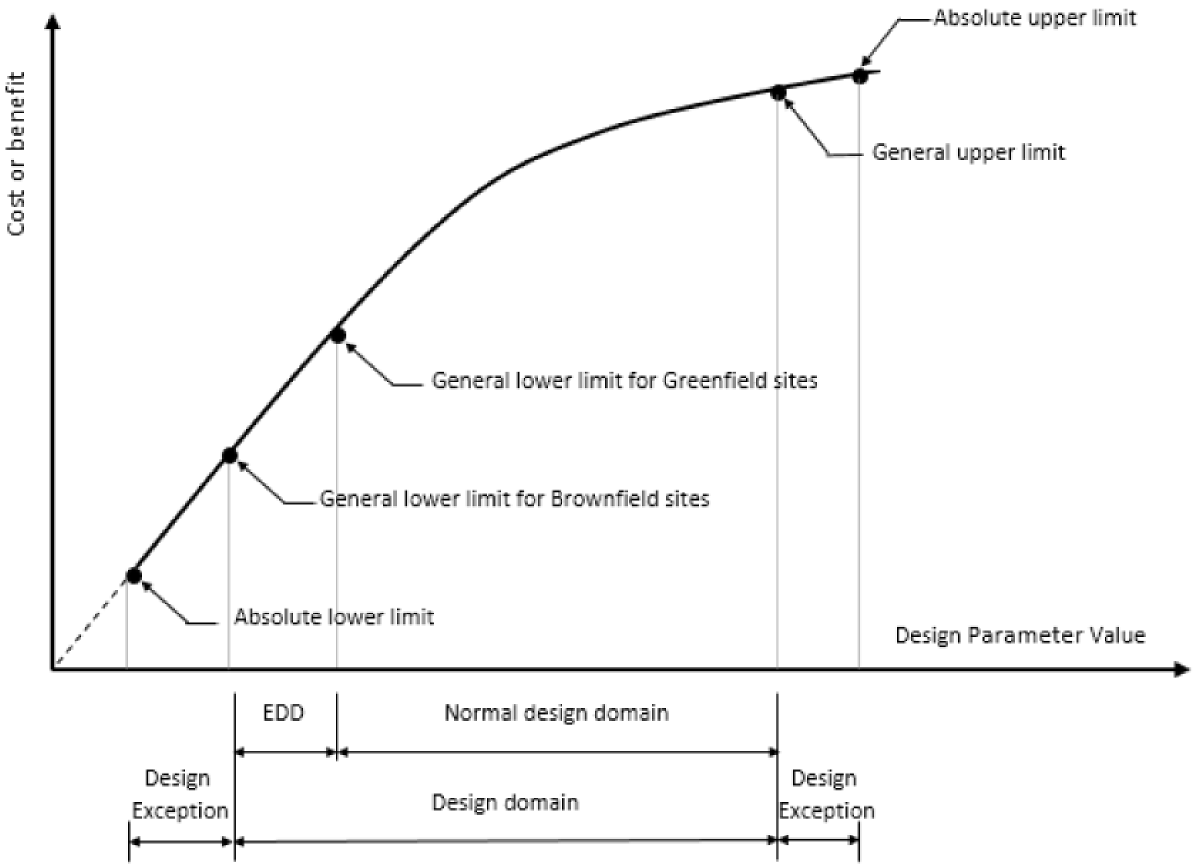
Values in the range denoted by Area 3 in Figure 4.2 fall below EDD because they become increasingly less likely to be supported on the grounds of reasonable capability. Any decision to use values in this range would need to be formally approved by the relevant road agency and supported by a well-documented justification and the use/installation of mitigating devices.

Any risk assessment justifying the adoption of a value within Area 3 must be unbiased and supported by crash analysis. Sometimes the drivers for adopting design exceptions such as these may be for social, environmental or economic reasons, however the risk assessment must show that the decisions associated with adopting such a low standard outweigh the potentially higher cost of FSI crashes.

Mitigating devices must comply with the requirements of relevant standards (e.g. signage in accordance with the *Manual of Uniform Traffic Control Devices* (AS 1742.2:2009) or the *Manual of Traffic Signs and Markings, Part 1* (NZ Transport Agency 2010)), including the posting of advisory speeds (where permitted), fencing to reduce potential hazards, and other devices.

The design domain approach places emphasis on developing appropriate and cost-effective designs rather than providing a design that simply meets ‘standards’. Figure 4.3 illustrates the concept that requires a designer to select a value for each design element from a range of values, considering the benefits and costs of each selection.

Figure 4.3: The design domain concept



Notes:

- *The value limits for a particular criterion define the absolute range of values that it may be assigned.*
- *The design domain for a particular criterion is the range of values, within these limits, that may practically be assigned to that criterion.*
- *Road Authority approval required.*

Source: Based on Transport Association of Canada (1999) and Queensland Department of Transport and Main Roads (2019).

Figure 4.3 shows that the design domain comprises a normal design domain (NDD), an extended design domain (EDD) and design exceptions (DE). The lower regions of the design domain represent values that would generally be considered less safe or less efficient, but usually less expensive than those in the upper regions of the domain. The decision on the values to adopt should be made using objective data on the changes in cost, safety and levels of service caused by changes in the design, together with benefit-cost analysis.

Such data is not always available, particularly data that relates changes in the values associated with specific design elements and parameters to safety performance. Designers should therefore refer to relevant documents, including this guide and research reports, to assess the potential effects of changes in values for the various design elements involved. The data chosen should also consider the importance of incorporating Safe System principles in the design.

Using this concept provides benefits to the designer as it:

- is more directly related to the road design process, placing a greater emphasis on developing appropriate and cost-effective designs rather than merely following prescriptive standards
- reflects the continuous nature of the relationship between changes in the design dimensions and service, cost and safety, as the designer must consider the impacts of trade-offs throughout the domain and not just where a standard threshold is crossed
- provides an implied link to the ‘factor of safety’, a concept commonly used in civil engineering design processes where risk and safety are important.

As a general principle, values in the upper part of the design domain should be selected when:

- designing new roads, particularly those in greenfield sites
- designing roads with high traffic volumes
- designing more important roads
- other parameters at the same location are approaching the minimum
- little additional cost is involved in the use of these values
- a significant crash history exists at a particular location.

Similarly, values in the lower part of the design domain may apply to works on existing roads involving improvements or restoration, where there is no significant crash history and where significant constraints exist.

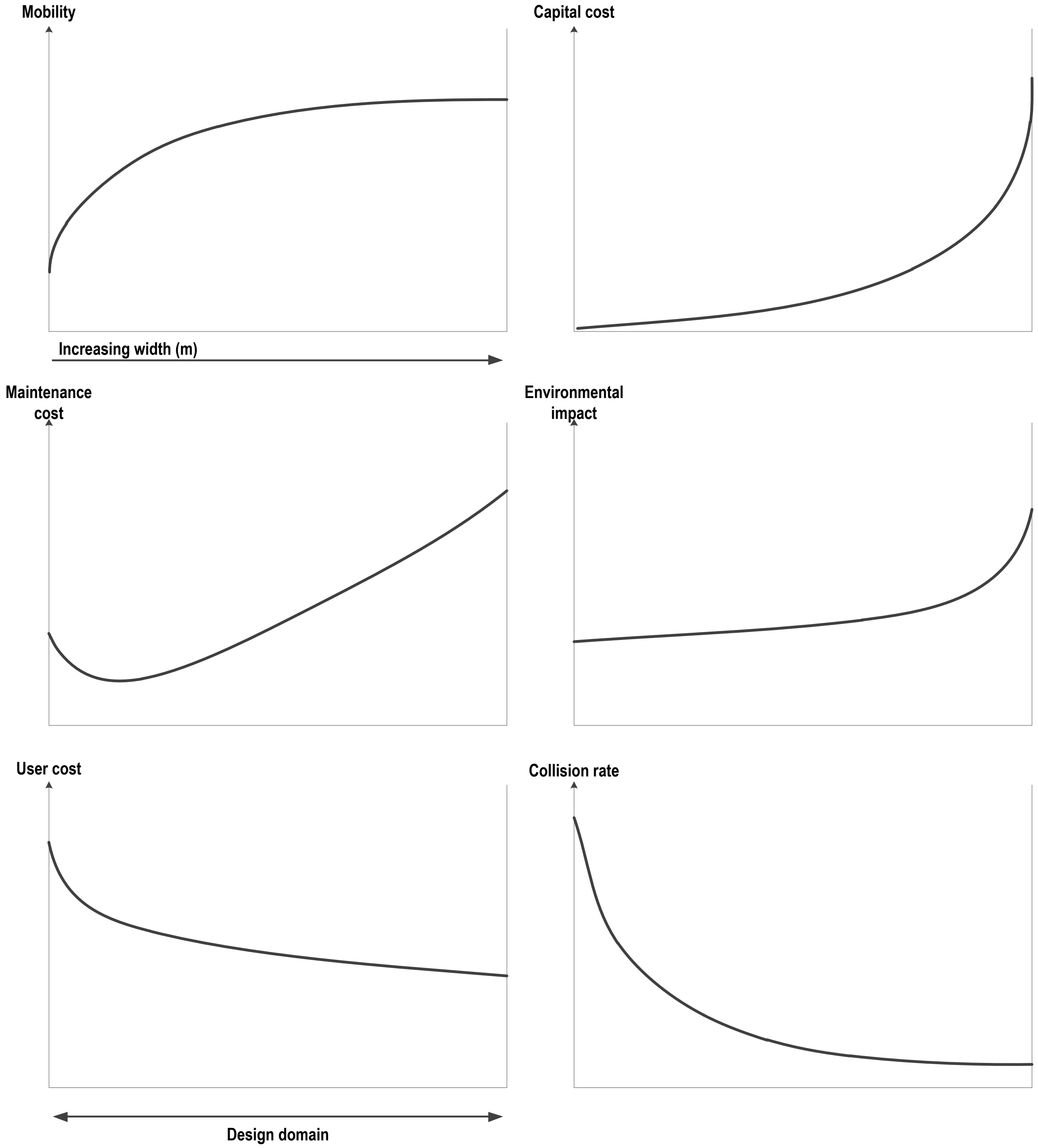
The use of values below the design domain (that is, even lower than the extended design domain) generally cannot be justified on engineering grounds and a risk assessment would be required to justify the decision. Any use of such values constitutes a design exception and must be formally approved by the relevant road agency after due consideration and documentation of all constraints, criteria and risks.

Figure 4.4 illustrates how the design domain concept might be applied to a single design parameter, and the example used is shoulder width. The graphs show that a value for shoulder width might be chosen that optimises the balance between costs and safety. Selection of a value within the domain will depend on a trade-off between the various benefits and costs. In other cases, values for several design parameters must be selected, with these parameters working together to optimise the design.

However, the designer must take into account the nature and significance of controls and constraints on the design. Often the designer will not be able to choose design dimensions that will satisfy all of the controls and constraints and compromise will be required. These engineering decisions call for knowledge, experience, insight and a good appreciation of community values.

To some extent, the design domain approach formalises the means by which previous manuals have defined the range of values within which the designer should operate. However, the design domain approach clarifies the extent of trade-offs and highlights the inter-relationship between the various elements of design. It encourages a holistic approach to design.

Figure 4.4: Design domain example – shoulder width



Source: Transport Association of Canada (1999).

4.5 Design Exception Process

Section 4.4 describes design exceptions (DE) as being values even lower than the extended design domain.

Design exceptions are most likely to occur due to challenging terrain; constrictions due to existing infrastructure, services, property boundaries, environmental conditions, cultural heritage and community expectations; and so on.

Wherever a DE is adopted, appropriate measures should be taken to mitigate any adverse effects of the exception. Stein and Neuman (2007) *Mitigation strategies for design exceptions* stated:

> *Designers should recognize, however, that design exceptions have the potential to negatively affect highway safety and traffic operations. For this reason, consideration of a design exception should be deliberative and thorough and a clear understanding of the potential negative impacts should be developed.*
>
> *If the decision is made to go forward with a design exception, it is especially important that measures to reduce or eliminate the potential impacts be evaluated and, where appropriate, implemented.*

4.5.1 Design Exceptions

Design exceptions are situations where the design does not meet client-developed (project-level) requirements or individual road design criteria from a referenced standard or EDD values if these are allowed by the road agency.

Generally, design exceptions should not be used where any one of the following applies:

- There is an accident history linked to the use of the design exception e.g. police accident reports indicate that limited visibility was a contributing factor to the accident/s. This is even more important in the following cases:
  - if more than one such accident is reported
  - mitigating devices are already in place.
- Use of the same, or similar, design exception has been known to cause safety problems elsewhere on the network.
- The value of the design exception is well outside the range of values of the design domain.
- The design exception is an isolated case, for example, if 40 km of roadway contains generous horizontal curvature except for one (or a few) very substandard horizontal curves. In this case, drivers become used to the general standard of horizontal curvature and are less likely to adequately perceive and negotiate the substandard element/s. This is different from a roadway comprising tighter, but more consistent horizontal alignment which would cause drivers to be more alert and have a greater expectancy of tight geometric elements.
- On road restoration or low volume road projects where the pavement is being replaced, especially if minimal earthworks are required.
- On road restoration projects comprising higher function and/or higher traffic volume roads.
- The parameter being considered is intersection sight distance. In this case, the EDD values are considered to be the lowest that should be provided.
- Where little effort and expense is required to avoid using the design exception.
- A design exception is combined with other geometric minima, especially other design exceptions. The greater the number of minima combined, the lower the likelihood that a design exception can be tolerated as one of these minima. Examples of combinations of design exceptions and other geometric minima that should generally be avoided are given in Table 4.4.

For use procedures for dealing with design exceptions, refer to the appropriate road agency.

Table 4.4: Combinations of design exceptions and other geometric minima that should be avoided

Design exception	Combination with other geometric minima
A substandard horizontal curve radius or substandard compound horizontal curve	• a tight crest curve, especially if the horizontal curve or compound curve starts after the crest curve • inadequate perception of, or sight distance to, the horizontal curve or compound curve • a hazardous roadside (e.g. larger trees, deep v-drains, steep fills close to the roadside) • inadequate superelevation • long drainage paths on the road surface • a floodway • a narrow carriageway (e.g. due to a narrow bridge or culvert or grid) • a steep downgrade • an intersection
A substandard vertical crest curve size	• a small radius horizontal curve or compound curve • a narrow carriageway • a hazardous roadside • a floodway just after the crest curve • a likelihood of hazards on the roadway (e.g. stock, fallen rocks) • an intersection
A narrow bridge or culvert (one-lane or two-lane of substandard width) or floodway	• limited visibility • steep downgrades leading to it • a small radius horizontal curve or compound curve • being located just after a small radius crest curve
Substandard sight distance	• a small radius horizontal curve or compound curve • a narrow carriageway • a floodway • a minor leg of an unsignalised intersection

Source: Arndt, Peters and Cox (2009).

4.5.2 Innovative and Emerging Treatments

Numerous innovative and emerging treatments are being considered by jurisdictions to improve road safety, for road operational efficiency, for environmental sustainability and to reduce costs.

Part 7 of the *Guide to Road Design* has been refocused to incorporate new and emerging treatments. It contains tested examples of experiences from Australian states and territories and from New Zealand.

4.5.3 Application of Guidelines

Design guidelines usually provide a range of acceptable values for each parameter (the ‘design domain’ discussed in Section 4.4), from which designers choose the most appropriate value. Construction cost considerations sometimes lead to designers selecting recommended minimum values that may or may not be appropriate for the particular circumstances. The use of a minimum value for a single parameter may be acceptable, but the use of minimum values for several inter-related parameters is generally not recommended, as the resulting design might be hazardous. Experience and judgement must be used in selecting the correct balance of values.

This part of the *Guide to Road Design* provides information and background material to help the designer choose appropriate characteristics for the elements of the design. Information presented in the guide is supplemented by additional material contained in the Commentary and References sections. However, the number of combinations of elements is large and can apply to a range of circumstances from local rural roads to major urban motorways. Consequently, this Guide cannot take account of all design situations and specific site circumstances. However, it does provide guidance to the designer in reaching appropriate decisions for each set of circumstances.

Design values that are not within the limits recommended by the relevant guide do not necessarily result in unacceptable designs, and values that are within those limits do not necessarily guarantee an acceptable or safe design. In assessing the quality of a design, it is not appropriate simply to consider a checklist of recommended limits. The design has to be developed with sound, professional judgement, and guidelines assist the designer in making those judgements.

In considering the results of any design process, it is important to step back and apply a reality check. The designer should be satisfied that the finished product is likely to best meet the various objectives of the project.

4.6 Design and Legal Liability

Road design guidelines are developed with consideration of the need to achieve a balance between the sometimes competing demands of operational requirements, safety, cost, and social and environmental impacts.

Design texts have historically used the concepts of absolute and desirable limiting values for each of the different design elements. The desirable limits identified where good practice should lie when allowed by the prevailing constraints, while the absolute limits defined design values that were outside of the desirable but were permissible subject to the professional judgement of the designer. Selection of design values outside the absolute limits was not considered an option.

The Guide to Road Design is intended to provide designers with a framework that promotes efficiency in design and construction, economy, and both consistency and safety for road users. However, the guide moves away from rigid design limits as the basis for achieving these goals and promotes the concept of ‘context-sensitive design’.

The intention is to allow designers the flexibility to exercise their critical, engineering judgement, for example, by choosing design values outside of normally accepted limits when prevailing constraints require, provided that they recognise their responsibility to be able to produce strong, defensible evidence in support of that judgement.

4.6.1 Legal Liability

Tort claims against road agencies have steadily risen in recent years. Tort is a legal term that refers to a civil wrong that has been committed. Negligence is a term used to refer to a classification of tort in which the injury is not intentional, but where there was a failure to use due care in the treatment of others compared to what a ‘reasonable man’ would have done. Liability is the responsibility to make restitution to the damaged party through an action or payment determined by a court.

Although these claims have been substantially relating to physical activities or road conditions, tort liability is potentially an issue for road designers.

Austroads or road agency guidelines, regulations, Australian standards, and research reports may be used in tort cases to educate the jury about the accepted level of practice for design. Expert witnesses may also be used, who in turn rely on written text to explain the accepted design practices to the court or a jury.

This does not mean that adherence to accepted practices and guidelines automatically establishes that reasonable care was exercised. Conversely, deviation from the guidelines does not automatically establish negligence. The best defence for a designer is to present persuasive evidence that the guidelines were not applicable to the circumstances of the project, or that the guidelines could not reasonably be met. It is highly recommended that designers document the rationale for their decisions.

If the justification documented by a designer completely describes the physical and environmental factors that make the variance from guidelines necessary, it is likely that this will be legally persuasive that the correct procedures were followed and ultimately the appropriate decision was made. It is also helpful to have statements by other design experts who concur with the decision in the documentation.

As a result of concerns about litigation, designers may be tempted to be very conservative in their approaches to highway design and avoid innovative and creative approaches to design problems. While it is important for designers to do their jobs thoroughly and carefully, avoiding unique solutions is not an answer. This may undermine design practice and limit growth in the profession. Designers need to remember that their skills, experience and judgement are valuable tools to be applied to solving design problems and that, with reliance on complete and sound documentation, tort liability concerns need not be an impediment to achieving good road design.

Engineers managing road networks and working on projects must understand their potential liability applying to engineering decision-making and policy decisions. Bobbermen and Creedon (2019) explain that engineering involves the management of risk. Engineers are, each and every day, asked to make decisions in the planning, design, development, construction, operation and maintenance of assets which can have major impacts on communities, worker safety, the environment and client businesses. There is a common expectation across each of these stakeholders that these assets will work safety and reliably in an environment of time constraints and financial limitations. There are several key considerations and deliberations that may influence the extent of legal risk and liability born by the engineer, as outlined below.

Highway immunity rule

On 31 May 2001, the High Court of Australia removed a long-standing 'highway immunity rule' enjoyed by highway authorities in Australia.[1] This rule provided that highway authorities were not liable for the condition of roads due to their actions or inactions unless they had knowledge of the defect prior to the incident causing the damage.

The highway immunity rule was subsequently reintroduced by most states and territories through the introduction of legislative changes.[2] Irrespective of that, all road agencies seek to ensure that they can demonstrate that they have in place reasonable measures to manage and maintain their road networks.

An engineer is legally accountable

An engineer can be challenged at any time to justify a decision made, irrespective of whether a standard was followed, augmented or put aside. While this accountability rests with the engineer, the liability for engineering decisions in a road context is sometimes perceived to be overstated because of the shared nature of road safety and parties involved. Nonetheless, it is important that engineers do not mistakenly take safety considerations lightly.

Individual skill and expertise

The consideration of an engineer's liability requires reference to both individual skill and expertise.

Importantly, an engineer that holds themselves out as being a specialist in a particular field of engineering will be required to exercise a higher standard of skill and care in carrying out their services.[3]

1 *Brodie v Singleton Shire Council* (2001) 206 CLR 512.
2 *Civil Liability Act* 2003 (QLD); *Civil Liability Act* 2002 (NSW); *Civil Liability Act* 2002 (WA); *Civil Liability Act* 2002 (Tas); *Civil Liability Act* 1936 (SA); *Civil Law (Wrongs) Act* 2002 (ACT); Unlike other jurisdictions, Victoria and the Northern Territory have not codified the highway immunity rule.
3 *Thwaytes v Sotheby's* [2015] EWHC 36 (Ch).

'Reasonably practicable' defence

When making a decision, an engineer (irrespective of whether he or she is following a standard) should always consider the need to justify the decision against a legal claim. One test which may be applied to justify an engineering decision, is whether the decision was ‘reasonably practicable’; that is, what would an engineer or group of engineers who are specialists in this particular field, have done under similar circumstances, albeit with the benefit of hindsight.

Not following a standard

Unless standards have been given the force of law (for example, work health and safety legislation), compliance with standards is not mandatory. Any failure to follow a particular standard cannot be said to be definitive proof of a breach of a duty of care. Decisions that deviate from standards, even though the circumstances justify such deviation, will always expose that engineer to potential accusations of negligence. The considerations of the individual’s skills and expertise and whether the decision was ‘reasonably practicable’ are key considerations for such decisions.

Judges do not operate as experts on appropriate professional procedure and instead rely on parties leading evidence as to what may be reasonable or normal conduct. Despite this, the court is the ultimate arbiter of fact. Therefore, it is open for the court to determine that, despite evidence indicating a particular course of action was standard or common industry practice, the conduct of a particular engineer involved an unacceptable degree of risk which should attract legal liability.[4]

Slavish compliance is not a complete defence

Conversely, slavish compliance with a standard is not a complete defence to any claim of negligence against the engineering decision-maker. While a significantly greater risk is born by an engineer when deviating from a standard, blindly following a standard does not provide the engineer with a legal defence when context and situations differ, extenuating circumstances exist, relevance is questionable, and complexity challenges naïve simplifications which may all cast doubt on the decision. Therefore, engineers need to have the requisite level of skill and expertise in order to correctly assess whether to follow a standard.

Providing evidence and peer professional opinion

A claim for breach of a duty of care against an engineering decision-maker will typically be assessed by considering an engineer’s professional and ethical behaviour, competence, and ability to substantiate the decision or involvement in the decision by:

1. explaining why standards are followed or not followed
2. providing documentary evidence, including a risk assessment, if a standard is not followed
3. showing that the decision was one that would have been exercised by a reasonably competent qualified engineer retained for the same purposes
4. clarifying the extenuating circumstances that exist before, during and after the event
5. recording statements of witnesses to the incident
6. recording of consultations with colleagues.

4 *Sidaway v Bethlem Royal Hospital* [1985] AC 871, 900; F v R (1983) 33 SASR 189, 194; *Battersby v Tottman* (1985) 37 SASR 524, 537; Barker et al 'The Law of Torts in Australia' (5th Ed) Oxford University Press, at 437.

Opportunity to innovate

The setting of a standard should not stifle innovation or continuous improvement and should always be seen in the context of a proactive approach to achieve the best outcome. However, engineers should not blindly or universally apply an innovation without evidence or risk assessment with a positive quantitative outcome risk. Pilot projects and trials involving increased monitoring are appropriate precautionary measures to check or test new ideas.

The Guide to Road Design Part 7: New, Emerging and Innovative Road Design Treatments documents an innovation framework for trialling these treatments.

4.7 Coordination of Disciplines

Design considerations include all the things that are important from an engineering and community perspective that impact the outcome of the design. They must include providing the safest possible design within the economic, social, and environmental considerations for the development of a road project. Design characteristics and values adopted must provide a satisfactory service to road users and be economically viable within the financial, topographical and environmental constraints that may exist.

At the highest level, the inputs will relate to project objectives that may be influenced by planning schemes, budgets, and government policies concerning transportation, sustainable development and the environment. At a project level the inputs may relate to detailed engineering requirements such as geotechnical information, availability of materials or the occupational health and safety of road workers.

There are many aspects to be considered in the planning and design of road projects. Table 4.5 provides a checklist of factors to be considered in relation to planning, site conditions, construction, maintenance and operational matters. The table also summarises the type and nature of the information, why it is needed, likely sources and references for further guidance.

Table 4.5: Checklist for design considerations

Design consideration	Type of information	Why needed	Nature of information	Likely source
PROJECT MANAGEMENT				
Project scope and objective	• Extent of the project site • Purpose of the project • Safety issues to be addressed • Project budget • Project timeline with milestone delivery	• Understand limitation of design brief and basis to the project • Appreciate the financial scope of the project that may need to be applied when selecting design criteria • Clearly define the expectations of the client/project sponsor	• Project brief containing key points such as where, why, purpose and scope of the proposed road improvements • Crash data analysis	• Client/project sponsor, e.g. road agency land developer
Risk management	• Written report highlighting issues raised by risk management, safety by design and constructability workshops and road safety audits	• Statutory obligation under the Workplace Health and Safety Act • Provide independent, specialist input about project risks, constructability risks and considerations and road user safety issues associated with the design	• Written report • Marked-up plans • Summary of risk and safety issues • Recommended action	• Independent road safety audit team via the project sponsor

Design consideration	Type of information	Why needed	Nature of information	Likely source
PLANNING FACTORS				
Land use/zoning	• Existing and proposed future adjacent land use	• Alignment and grade-line controls • Clearance/screening/land scaping requirements • Social and socio-economic effects (e.g. separation of communities)	• Planning scheme maps • Aerial photographs/ surveys	• State/local planning authorities • Community consultation
Right-of-way boundaries	• Road reserve boundaries	• Alignment and grade-line controls • Cross-section controls • Intersection treatments	• Planning scheme maps • Survey plans	• State/local planning authorities
Access restoration	• Existing and proposed points of access to roadway • Design vehicles for access points	• Alignment and grade-line controls • Intersection design	• Planning scheme maps • Photogrammetric/ field survey	• State/local planning authorities • Community consultation
Other infrastructure	• Provision for assets in road reserve/on road • Controls on crossing of assets • Drainage controls • Clearance requirements • Rail level crossings	• Alignment and grade-line controls • Cross-section controls • Drainage design • Relocation and protection of public utilities • Economic provision for future public utilities	• Clearance diagrams • Minimum cross-section requirements • Drainage outfall conditions (e.g. maximum discharge) • Policy and regulatory requirements	• Other authorities • Local government • Service authorities • Public transport, road and rail • Airports
SITE FACTORS				
Geographical factors				
Topography/ terrain	• Topography of route alignment and adjoining land	• Alignment and grade-line controls • Drainage design	• Topographical maps • Photogrammetric/ field survey	• Field investigation • State survey/mapping department
Note Topography can have a significant effect on the costs of achieving a high-standard road alignment. In flat terrain a high-standard road can generally be achieved at an acceptable cost, while in steep and mountainous country a marginal increase in standard may rapidly escalate costs. A higher standard in undulating terrain can also substantially increase costs if larger cuttings and fills are required. To ensure that limited funds are effectively spent on appropriate designs, due regard must be given to designing with the terrain rather than against it. For example: • balanced earthworks limit the cost of importing additional fill materials or disposing it off-site • ensuring that the grade-line stays above non-rippable rock negates the need for blasting • keeping the grade line above the water table will limit moisture ingress to the pavement and could avoid the need for drainage blankets.				

Design consideration	Type of information	Why needed	Nature of information	Likely source
Geotechnical conditions [see Appendix B for details]	• Location and nature of rock/soil • Location and nature of groundwater • Slope stability assessment	• Alignment and grade-line controls – maximum/minimum cut/fill heights • Cross-section controls – maximum/minimum batter slopes • Pavement design • Subsurface drainage design • Drainage design – erosion, water quality (e.g. saline groundwater) • Construction cost/feasibility assessment	• Geological maps • Seismic investigation • Core samples • Test pits • Laboratory testing of samples	• Field investigation • Specialist reports • Local authorities • State environment protection authority • State survey/mapping department
Runoff and drainage	• Flood levels/discharges • Water management practices on adjoining land	• Alignment and grade-line controls • Drainage design • Water quality treatment facilities • Major waterway structures design	• Historical flood records • Computer modelling of catchments • Calculations of peak discharges • Inundation plans showing flood extent/frequency	• Weather Bureau records • Local drainage authority • Australian Rainfall and Runoff (IEAust publication) • Specialist reports
Rainfall	• Rainfall records • Rainfall intensity	• Drainage design • Water quality treatment facilities	• Annual total • Seasonal distribution • Storm rainfall intensities	• Weather Bureau records • Australian Rainfall and Runoff (IEAust publication)
Temperatures	• Seasonal variation maximum/ minimum	• Alignment and grade-line control (e.g. icy conditions) • Pavement design (maximum/minimum temps for surfacing, treatments for icy conditions)	• Frequency, duration and nature of extreme conditions	• Weather Bureau records • Specialist reports
Built environment				
Utility services	• Location of water, sewer, power utilities, telecommunications	• Avoid clashes with, or adjust, existing infrastructure	• Locations of, or plans for, services	• Utility authorities
Urban design	• Topography • Vegetation	• Co-ordination of horizontal and vertical geometry • Landscape design • Structure type	• Scenic values • Natural landscape • Areas of visual significance	• Planning authorities • National park authorities • Environment authorities

Note Urban design may involve the view of the road from the non-user's perspective as well as the view of the surrounding area from the road. Urban design is particularly important for roads in scenic areas, and may relate, for example, to the co-ordination of horizontal and vertical geometry, the slopes adopted for batters or landscaping within the road reserve. Urban design may also influence the choice of standards – for example, the character of neighbouring land uses may dictate the style and dimensions of noise barriers.

Design consideration	Type of information	Why needed	Nature of information	Likely source
Environmental factors				
Note Environmental factors need to be considered in major public works such as road construction and are also an essential part of the road design process. A road is just one element in the environment, as discussed in Section 2.2.5. Environment in this sense refers to the total social and natural environment. A road should desirably be located and detailed so as to complement the environment and surrounding communities rather than to harm them. For example, a valuable resource such as an adjacent area of old-growth forest may merit preservation in its own right and this could restrict the land available for expansion of a road's right-of-way.				
Flora	• Location, extent and nature of vegetation in road reserve and on adjacent land	• Alignment and grade-line controls • Cross-section controls by limiting footprint • Approvals for clearing from other authorities • Approvals from state and federal environmental authorities	• Plans showing different vegetation types, tree locations etc. • Aerial photographs	• Field investigation • Specialist reports • Local authorities • State environment protection authority • Special interest groups
Fauna	• Location and extent of fauna habitat • Location and extent of fauna movement corridors	• Alignment and grade-line controls • Cross-section controls by limiting footprint • Approvals from state and federal environmental authorities	• Plans showing different vegetation types – tree locations • Aerial photographs	• Field investigation • Specialist reports • Local authorities • State environment protection authority • Special interest groups
Noise	• Existing noise levels at adjacent properties • Predicted noise levels from proposed roadway	• May influence alignment/grade-line • Determine noise attenuation measures required	• Noise level measurements/ calculations at individual sites • Noise contour maps	• Field investigation • Specialist reports
Air quality	• Existing air quality at adjacent properties • Predicted effect on air quality from proposed roadway	• May influence alignment/grade-line	• Existing air quality measurements • Calculations of impact on air quality	• Field investigation • Specialist reports • State environment protection authority
Water quality	• Condition of adjacent waterways/outfalls	• Location of drainage outfalls • Design of road runoff water quality treatment measures	• Records of previous testing/evaluation • Water sample test results • Pollutant/nutrient levels	• Drainage authority • State environment protection authority • State legislation (e.g. state environment protection policies) • Filed Investigation
Contaminated soil	• Location, extent and nature of contamination	• May influence alignment/grade-line • Treatment measures required – removal, minimum cover etc.	• Records of previous land use • Investigation sample results • Expert reporting	• Local authorities • State environment protection authority • Field investigation

Design consideration	Type of information	Why needed	Nature of information	Likely source
Cultural/heritage factors				
Land areas that may require preservation or protection	• Location and significance of indigenous and post-settlement heritage sites	• Alignment and grade-line controls • Cross-section restrictions • Minimum clearance requirements • Approvals from state and federal heritage authorities	• Archaeological reports • Local historical records	• Field investigation • Specialist reports • State/federal heritage authorities • Local historical societies • Local indigenous communities/ groups
STATUTORY APPROVALS				
Environmental clearances	• Requirements to satisfy environmental legislation	• To develop, exhibit, and determine environmental statements	• Nature and extent of study and documentation required • Exhibition and approval processes	• State and federal environment agencies
ASSOCIATED DESIGNS				
Pavement	• Pavement design	• Impacts on formation and drainage requirements	• Materials, depths, design life	• Pavement designer – road agency or consultant
Drainage	• Volume and nature of runoff	• Possible constraints on geometric design • Obtain necessary environmental clearances	• Runoff quantities, discharge points • Potential spills • Environmental constraints	• Road agency • Environmental agencies
Ultimate development, staging	• Future traffic • Future development	• Assess staging options	• Traffic growth projections • Planning, development proposals	• Road agency traffic section • State and local planning agencies
Geotechnical design	• Suitability of materials for construction purposes	• Formation design • Environmental issues • Construction materials	• Material types and characteristics • Contamination	• Road agency investigations
Safety Assessment of the detailed design	• Safe system assessment framework scoring matrices	• Demonstrate alignment with safe system objectives	• Safe system assessment framework scoring matrices	• Road agency or consultant
CONSTRUCTION FACTORS				
Constructability	• Construction staging proposals • Traffic management proposals for existing roads • Practical construction practices	• Assessment of feasibility to construct • Assessment of impact on community during construction	• Construction staging plans • Traffic management plans	• Road agency • Local government • Community consultation • Construction industry

Design consideration	Type of information	Why needed	Nature of information	Likely source
Availability of materials	• Assessment local material properties – earthworks and pavement • Local material supplies	• Batter stability, settlement, durability assessment • Pavement design	• Geotechnical reports • Quarry product information	• Field investigation • Specialist reports • Road agency • Local extractive industries
Provision for traffic facilities and Intelligent Transport System (ITS)	• Traffic projections, development potential • Developments in ITS	• Forecast of likely traffic developments and further enhancement of facilities • Make provision for ITS facilities	• Traffic forecasts • ITS state of the art	• Road agency • Research organisations
ASSET MANAGEMENT				
Whole-of-life costs	• Design life of elements with finite useful life (e.g. pavements) • Cost estimates for alternatives, replacement and maintenance • Crash cost savings	• Assessment of alternatives to determine most economical treatment over given time period, and not just initial construction cost	• Design life estimates • Maintenance cost estimates • Replacement cost estimates • Traffic growth estimates	• Road agency project evaluation practices
Maintainability	• Roadside vegetation management practices • Drainage facility management practices • Material stability assessment • Maintenance budget constraints	• Cross-section – maximum batter slopes • Maximum/minimum grades for drains • Water quality treatment facility design	• Maximum slopes for operation of maintenance equipment (e.g. mowing) • Geotechnical reports on material stability • Maintenance practices	• Road agency • Local government • Local drainage authority
INDUSTRIAL FACTORS				
Occupation Health & Safety (OH&S) for construction and maintenance staff	• Legislative requirements • Approved work practices	• Cross-section • Road safety barrier positioning	• Clearances between worksites and traffic • Worksite safety barrier requirements • Worksite traffic management practices	• Codes of practice • State OH&S • Road agencies
OPERATIONAL FACTORS				
Ultimate design and staging	• Ultimate traffic volume and cross-section requirements	• Establish cross-section standards and provision for future widening • Provision for future intersection modifications (e.g. signalisation)	• Future traffic volume predictions • Land development proposals/plannin g schemes	• State/local planning/road agencies • Specialist reports

Note Where land uses are changing and traffic demand is growing it is likely that there will be a need for future road improvements. Where it is obvious that medium-term requirements are different from the best short-term design for a particular road, it is often possible to modify the design slightly to provide better options for the future. While this might commit some funds and prevent their use on other current projects, the effect can be much less than if a longer-term design is adopted in the first instance.

Wherever practicable and appropriate, designers should consider an ‘ultimate’ layout for a road and use this as the basis for the short-term design. Examples would include at-grade intersections configured to allow for future duplication and grade separation, and unsignalised intersections provided with cable ducting for future signalisation.

Design consideration	Type of information	Why needed	Nature of information	Likely source
Provision for traffic facilities	• Rest area requirements • Intelligent transport systems • Traffic monitoring	• Alignment and grade-line controls • Cross-section restrictions • Minimum clearance requirements	• Highway development strategies • Traffic management strategies	• Road agency • Community consultation
Provision for special users	• Policies/provisions for public transport, non-motorised transport and disabled users	• Bus lanes • High occupancy vehicle lanes • Bicycle lanes • Truck lanes • Crossings	• Proposals for use by specialist modes • Required provisions for disabled users	• Planning authorities • Transport agencies (as distinct from road agencies)
Access control	• Functional road classification	• To determine extent of access control required	• Status of road, current or planned	• Road agency • Planning authority
Note Abutting landowners normally have a right of access to the road reserve adjacent to their property, but not necessarily to every portion of the reserve. The rights of the owner must be balanced against the right-of-passage of the public on the reserve. In general, the right-of-passage of the public dominates over the rights of the adjoining owner (Lay 1985, p. 51). Depending on the classification of the road, this will generally lead to the road agency having a greater or lesser degree of control over access to public roads. The degree of control, and determination of access points, will frequently be determined by the planning process. The control may range from freeways with access only via grade-separated interchanges, arterial roads with service roads and/or limited points of access, to local roads with full and uncontrolled access available. The adjoining local road network may also be modified to reduce the number of intersections with the arterial road and provision may be required for grade-separated intersections.				
ITS operations	• Road ITS operational strategies	• Increases the benefits derived from a given investment • Enables a better designed facility to respond to incidents and road works • Reduces the cost of future deployment of ITS • Improves the effectiveness of operational schemes	• Operational strategies, plans, methods etc. from road operators and other stakeholders • Hierarchy structure with respect to road operations • Considerations of the system engineering approach to ITS and its impact on operations	• Road agency ITS operational staff • Other road user bodies that may require input to ITS operations (e.g. private toll roads, emergency services etc.) • (Note: Operational strategies and other policies and strategies should be contained in one document as a consistent source reference for designers and other stakeholders)
ECONOMIC FACTORS				
• *Note* Economic analysis of a project considers the range of costs and benefits that fall to a wide variety of users across the community. Such analysis will often justify a high standard and high-cost project because of the substantial benefits that flow to road users. However, any project must compete for funding with a range of other projects, just as a government-funded road program must compete with other government programs for budget funding.				
Geometric design, traffic capacity	• Economic analysis	• Project priority	• Benefit-cost ratio • Net present value	• Road agency

Design consideration	Type of information	Why needed	Nature of information	Likely source
FINANCIAL FACTORS				
Note Separately from economic benefits and costs, the level of finance available may influence the standard adopted for a road project, depending on traffic demand and the project objectives. For example, the choice of a higher-speed alignment may result in a disproportionate increase in cost compared to an alignment with a marginally lower speed. While it may be justifiable in economic terms, financial constraints may render the higher standard unaffordable.				
Geometric design, traffic capacity	Financial	Whether project can proceed	Available funds	Road agency State/federal treasury
TRAFFIC FACTORS				
Geometric design	• Amount of traffic	• Number of lanes • Overtaking lanes	• Traffic volumes • Daily and hourly distribution • Traffic growth projections	• Road agency
Note Traffic volume is a basic consideration in the design of roads. It influences the need and justification for works, the comparison of alternative solutions, the selection of road types, and the selection and application of design standards. For intersection designs, the volume of traffic on each leg of the intersection and the turning movements are determining factors in the selection of the type of intersection.				
Geometric design	• Type of traffic	• Lane widths • Longitudinal design • Overtaking lanes • Curve widening • Bicycle lanes	• Classification counts	• Road agency
Note The effect of heavy vehicles in the traffic stream is to lower the level of service provided by the road because: • a heavy vehicle takes up more space than a car, so it is equivalent to more than one car in traffic volume terms (more so on gradients) • the disparity in speeds between light and heavy vehicles leads to increased queuing and overtaking requirements. The proportion of heavy vehicles also influences the structural design of the pavement and the need for overtaking lanes and widening on curves and turning roadways.				
Geometric design	• Design vehicle	• Lane widths • Vertical clearances • Curve radii and widening • Provision for oversize vehicles	• Vehicle dimensions • Relevant industrial developments	• Road agency • Planning authority
Geometric design	• Allocation of road space	• Provision for special users	• High occupancy vehicle needs • Public transport demand • Bicycle, pedestrian and disabled provisions • On-road parking needs • Breakdown-lane needs	• Road agency • Public transport providers • Planning authorities
Note Roads, particularly those in urban situations, are required to cater for general traffic flow and also provide for the special needs of public transport, bicycles and pedestrians. Incorporating facilities into the road design to cater for vulnerable road users should follow the Safe System approach. It is often difficult or impossible to provide special facilities for these competing uses on existing and new roads where the right-of-way or width available for pavement is constrained. In such situations the distribution of road space (and time, in the case of traffic signals) should relate to the network strategy and the role the road is expected to fulfil. For example, on public transport routes the provision of a bus lane or better tram stops may be the highest priority in relation to network strategy and government policy.				

<table>
<tr><th>Design consideration</th><th>Type of information</th><th>Why needed</th><th>Nature of information</th><th>Likely source</th></tr>
<tr><td>Geometric design</td><td>• Design speed</td><td>• Curve radii
• Sight distance
• Intersection design</td><td>• Expected and desired speed distribution of vehicles</td><td>• Road agency</td></tr>
<tr><td colspan="5">Note Design speed is a most important parameter in road design. It is a speed fixed for the design and correlation of those geometric features of a carriageway that influence vehicle operation. Design speed should not be less than the intended operating (85th percentile) speed.
• A good design combines all geometric elements into one harmonious whole, consistent with the speed environment, so that drivers will be encouraged to maintain a reasonably uniform speed over as great a length of road as possible.
• Speed parameters are noted in Section 4.1.3 and discussed in greater detail in Part 3 of the Guide to Road Design (Austroads 2016a).</td></tr>
<tr><td>Geometric design</td><td>• Design period</td><td>• Provision for enhanced traffic capacity when required</td><td>• Length of design period
• Traffic growth projections</td><td>• Road agency</td></tr>
<tr><td colspan="5">Note The design of roads is usually based on the traffic expected to use them over their design life. This requires the selection of a design year and the estimation of the volume and composition of the traffic likely to use the facility in that year.
Some elements of a road may have an extremely long life. For example, the right-of-way, basic earthworks and the horizontal and vertical alignment could be expected in many cases to have a life of 50 to 100 years (or even more). Bridges are commonly designed for a life of 100 years, though in practice changes in land use, traffic volume and composition, or road realignment may mean they are bypassed within 30 to 50 years. Pavements could have a life of 20 (normal duty) to 40 (heavy duty) years if adequately maintained.
In terms of traffic service, a period of 15 or 20 years may be chosen for the design of rural highways. For intersection design, the choice of a 20-year period for the design may be unrealistic and many new facilities may reach capacity in a relatively short period of time. However, it is relatively easy to upgrade an intersection in stages to provide additional capacity, provided adequate provision is made in the initial concepts. In some cases, intersections may progress from a basic design, to provision of turning and slip lanes, signalisation, and finally to grade separation.
In some cases, a staged approach may be taken where, for example, a divided road is planned and designed for the longer term, and one carriageway is constructed as a two-way two-lane road to provide satisfactory service for the first 10 to 15 years. In such cases the road reservation may be acquired initially or reserved in a planning scheme.</td></tr>
<tr><td>Geometric design</td><td>• Desired level of service</td><td>• Determination of initial and future capacity to be provided
• Input to economic analysis</td><td>• Proposed grade lines
• Proposed design speeds
• Traffic volume and composition
• Daily and hourly distribution
• Traffic growth projections</td><td>• Road agency</td></tr>
<tr><td colspan="5">Note Level of service is defined as a qualitative measure describing operational conditions within a traffic stream, and their perception by motorists and/or passengers.
A level of service definition generally describes these conditions in terms of factors such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort and convenience, and safety. In general, there are six levels of service, designated from A to F, with level of service A representing the best operating condition (i.e. free flow) and level of service F the worst (i.e. forced or breakdown flow).
The different levels of service can generally be described as follows:
• Level of service A is a condition of free flow in which individual drivers are virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to manoeuvre within the traffic stream is extremely high, and the general level of comfort and convenience provided is excellent.
• Level of service B is in the zone of stable flow and drivers still have reasonable freedom to select their desired speed and to manoeuvre within the traffic stream, although the general level of comfort and convenience is a little less than with level of service A.
• Level of service C is also in the zone of stable flow, but most drivers are restricted to some extent in their freedom to select their desired speed and to manoeuvre within the traffic stream. The general level of comfort and convenience declines noticeably at this level.</td></tr>
</table>

Design consideration	Type of information	Why needed	Nature of information	Likely source
• Level of service D is close to the limit of stable flow and is approaching unstable flow. All drivers are severely restricted in their freedom to select their desired speed and to manoeuvre within the traffic stream. The general level of comfort and convenience is poor, and small increases in traffic flow will generally cause operational problems. • Level of service E occurs when traffic volumes are at or close to capacity, and there is virtually no freedom to select desired speeds or to manoeuvre within the traffic stream. Flow is unstable and minor disturbances within the traffic stream will cause breakdown. • Level of service F is in the zone of forced flow. With it, the amount of traffic approaching the point under consideration exceeds that which can pass it. Flow breakdown occurs, and queuing and delays result. Conditions affecting level of service include the roadway, terrain, driver population, traffic mix and characteristics, and traffic controls. The concepts of level of service are well described in the US *Highway Capacity Manual* (Transportation Research Board 2010) and the *Guide to Traffic Management Part 3* (Austroads 2020b), in addition to the *Guide to Road Design.* For pedestrian facilities, the basic concept of level of service applies but the details are often more complex than a simple translation of the above 'traffic flow' approach would provide. For crossing facilities, pedestrian delay is a prime consideration. Many other factors including perceptions of quality and comfort contribute to practical (perceived) levels of service. Further advice on pedestrian level of service is given in the *Guide to Traffic Management Part 3* (Austroads 2020b).				
Geometric design	• Associated designs	• Interactions between design requirements	• Structures • Lighting • Landscape	• Road agency
Intersection design	• Amount of traffic	• Type and nature of intersections • Traffic controls	• Traffic volumes on main and intersecting roads • Turning volumes	• Road agency
Intersection design	• Type of traffic	• Corner radius • Bicycle lane treatments • Crossing design	• Classification counts • Pedestrian levels	• Road agency

4.8 Delivery Considerations

4.8.1 Mechanisms to Deliver Projects

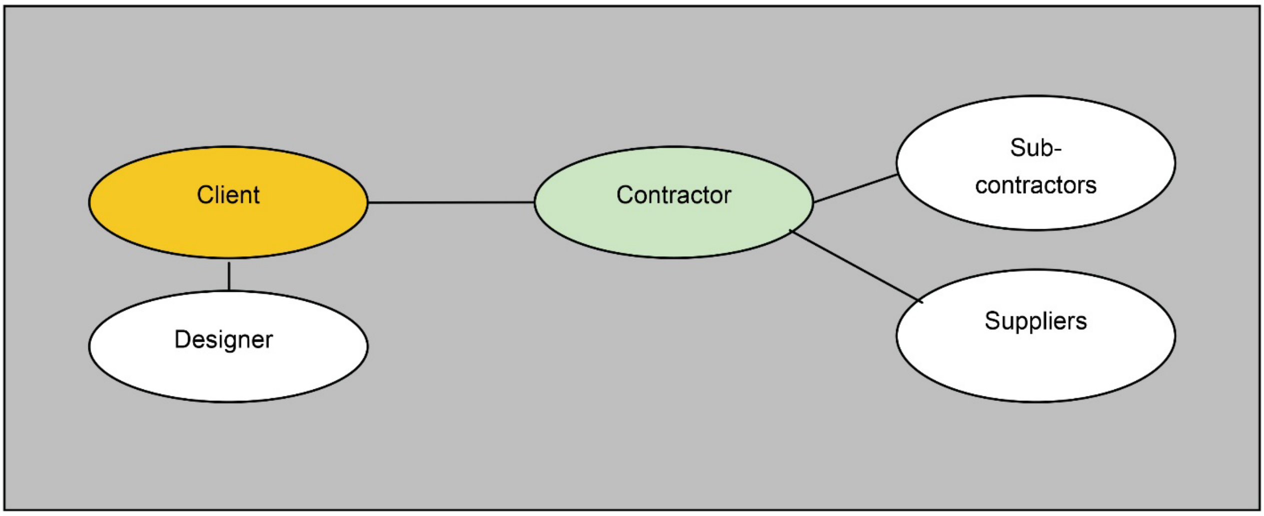
The mechanism chosen to deliver the construction of the project determines the degree of detail (design phase) required in the outputs from the client (Appendix A.1.4). The principal methods available to and used by clients are:

- Construct Only (C)
- Design and Construct (D&C) and Maintain (DCM)
- Early Contractor Involvement (ECI)
- Alliance.

Construct Only (C)

These contracts separate design and construction responsibilities by awarding an independent designer and a separate construction contractor, as illustrated in Figure 4.5. The design is either conducted in-house or is awarded to a design consultant to prepare drawings, specifications and tender documents.

Figure 4.5: Relationship between the client and the Construct Only contractor



Source: Main Roads Western Australia.

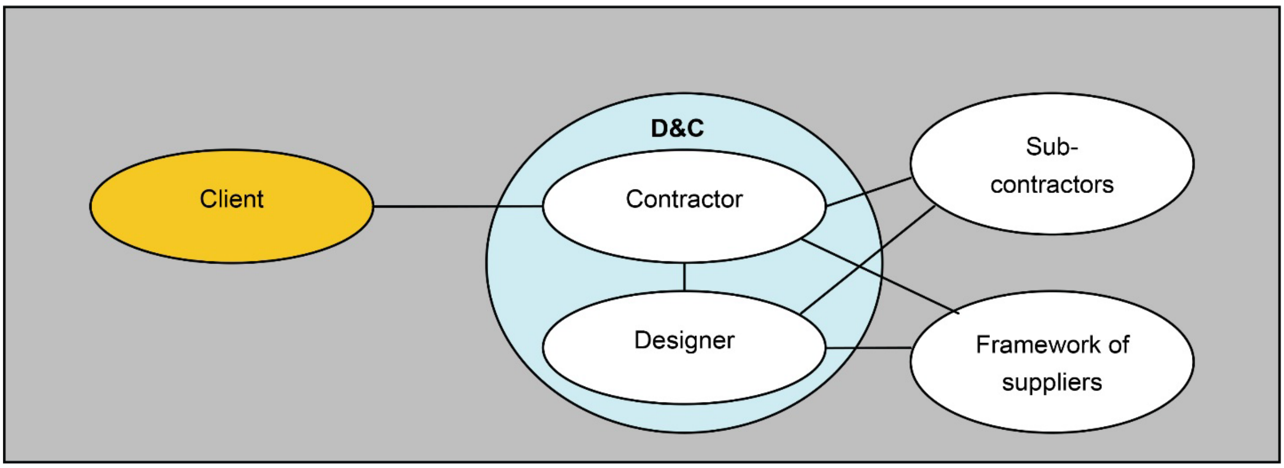
The successful implementation of the Construct Only contract relies on fully complete, accurate designs and tender documents. The design documentation typically comprises a suite of signed and approved drawings (often supplemented with computer-based string information), a schedule for pricing and a job-specific specification. The design is fully complete prior to construction (Phase 3 output) and the final selection of the contractor is typically based on the most competitive and conforming tender.

Design and Construct (D&C) and Maintain (DCM)

D&C contracts combine the design and construction responsibilities by awarding a joint contract to a single contractor (contractor, consortium, joint venture) typically under a lump sum contract as illustrated in Figure 4.6. To enable the contractor to bid for the D&C it is normally sufficient for the client to provide Phase 2 design plans showing the preferred design solution but without the supporting detailed design of all elements. Contractors then prepare a proposal demonstrating their intent and ability to complete the design as well as undertaking the construction. The contractor takes responsibility for the design documents such that they will comply with nominated design standards and guidelines, and that the design documents will be made available to the client complete and free from error.

A variation on the D&C contract is a DCM contract which includes a requirement for an extended maintenance period for the constructed work.

Figure 4.6: Relationship between the client and the Design and Construct contractor



Source: Main Roads Western Australia.

Early Contractor Involvement (ECI)

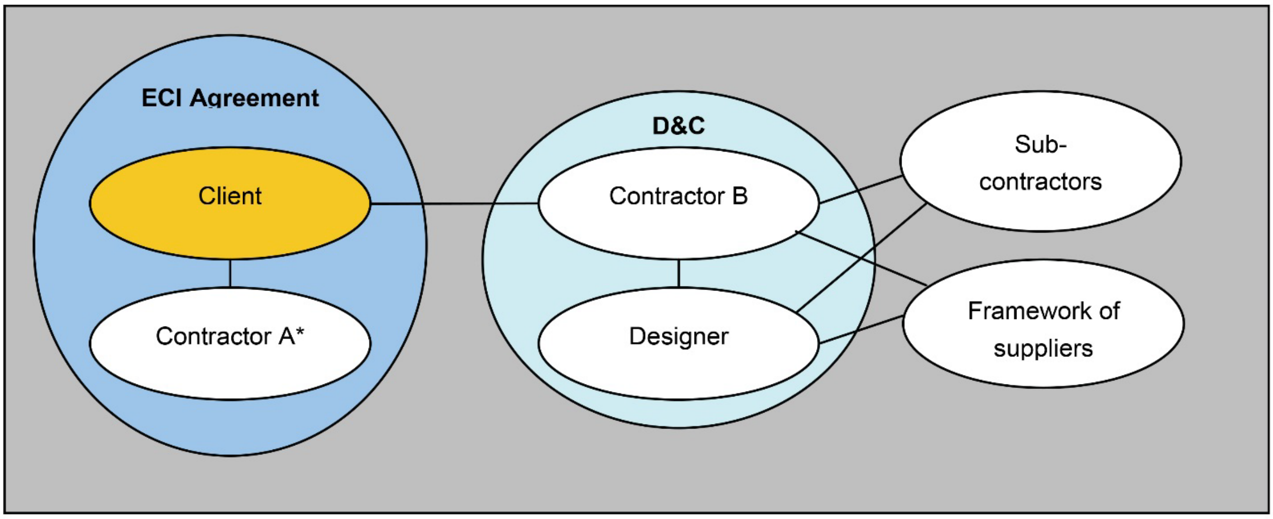
This form of delivery utilises an agreement and is normally associated with a subsequent Design and Construct contract. Generally, the two are awarded to one contractor to undertake the design and construction under a lump sum contract (Figure 4.7).

The successful implementation of the ECI relies on well-scoped tender documents, performance criteria and realistic delivery timeframes. The characteristics of the ECI are that:

- resources are applied during the construction planning phase to maximise benefits during construction
- scope can be defined during the ECI phase
- the client can exercise greater control.

As for a D&C, it is normally sufficient for the client to provide Phase 2 output design plans showing a preferred solution but without the supporting detailed design. The detailed design is developed as a partnership between the nominated designer and the contractor, with input from the client.

Figure 4.7: Relationship between the client and the Early Contractor Involvement contractor



* Contractor A is generally also Contractor B.

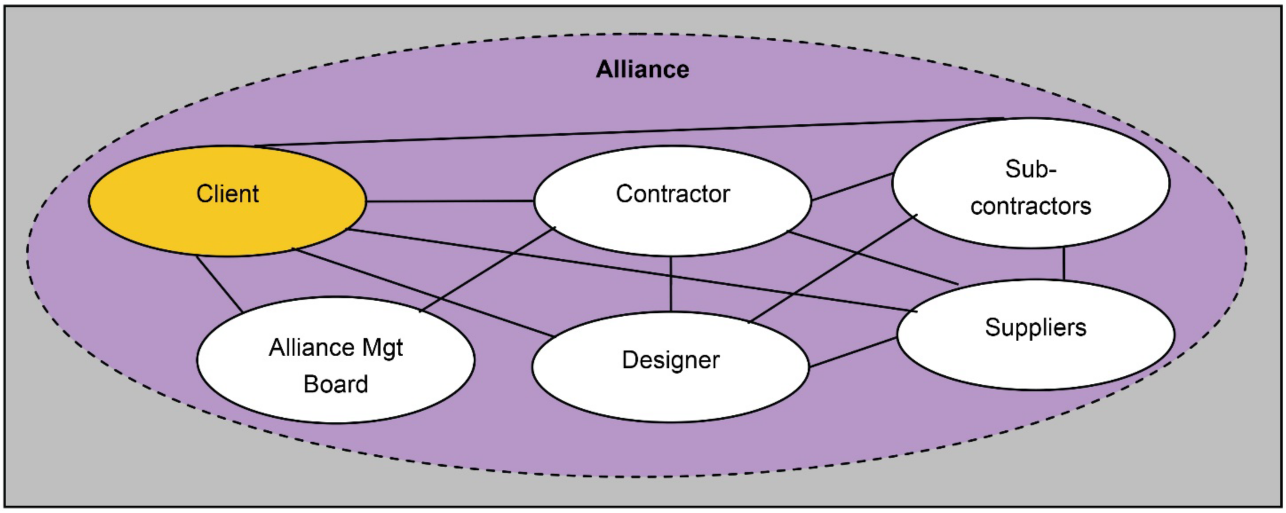
Source: Main Roads Western Australia.

Alliance

The Alliance is a form of the Design and Construct contract with special contract conditions designed to align targets and enhance collaboration. The client will usually commission a contractor to develop the project details based on a Phase 2 design output. The Alliance contract is awarded to the most suitable proponent and the client works collaboratively with the contractor under a legal agreement. The relationship between the client and the contractor is illustrated in Figure 4.8.

Of primary importance is that project objectives are known and documented, including reference to design standards and guidelines with which the final design must comply.

Figure 4.8: Relationship between the client and the Alliance contractor



Source: Main Roads Western Australia.

The main benefit of the Alliance contract is that the risks are shared between the client and the contractor under a contractual framework where commercial interests are aligned with project outcomes.

4.8.2 Workplace Health and Safety/Safe Design

Overview

Decisions made during the design process influence the way in which a project will be built, maintained, operated and ultimately decommissioned. The risks posed to workers vary with the different approaches taken and there is an onus on designers to minimise those risks wherever possible. This obligation to worker safety is different to meeting road user safety objectives, although one solution may meet both aims.

Fundamentally, designers should ask themselves the question, 'How can I prepare my design to improve the health and safety of all people involved in the construction, maintenance, operation and decommissioning of this project?'

It should be noted that whilst this question is posed to designers, it is unlikely that they will be making these decisions in isolation. The ultimate authority will depend on the road agency but it would be expected that a team with broad skills including those involved in approval of the project scope, the project manager and representatives from the target work groups will assist with making these decisions.

The decisions made in this regard should then be documented. Typically, this would occur within the design report, but some design projects may be sufficiently large and/or complex that a separate report is appropriate. It should be noted that some road agencies require a separate report.

The following outlines a generic process which can be followed to help designers identify potential safety issues and thereby implement mitigation measures. These considerations may form part of the documentation for the design.

These considerations are required at all phases of design, typically at similar times to road safety audits. Initially, the safety risks identified for each option in the first phase (Section 4.2.1) would form one input into the decision-making process to establish the preferred option. Then those documented risks would be passed to the next phase (Section 4.2.2). They would be refined and indeed may change as more detail is developed for the preferred option. In the third phase (Section 4.2.3), final decisions are taken about whether the design can be changed to influence occupational health and safety. Ultimately, some matters will be left for the constructor to handle, based on their construction methodology, choice of construction plant, choice of materials etc.

It is important to review the interaction between designed components to ensure that they collectively deliver safe operations.

Scope

The procedure is relevant for application to all road and traffic design projects and to all phases of design as described above.

The project stages to be addressed during the safe design development include:

- construction
- maintenance
- operation
- decommissioning.

For each stage, safety risks to all likely project users are to be considered, including:

- preconstruction activities (survey, geotechnical investigations, other site investigations)
- construction groups
- maintenance workers
- operations, general and specified users, other workers likely to work within the road reserve utilities, tram/bus shelter cleaners
- demolition workers.

Regular site visits and consultation with target groups should be maintained during the prescribed phases to assist with continuous improvement in the design checklists.

Checklists are discussed further in Appendix A.3.4.

Documentation

The documentation, probably a part of the design report for the project, is a record of the identification of occupational health and safety (OH&S) risks pertaining to the project and the steps taken to eliminate or mitigate those risks through the project's life cycle.

As such it is a document that is created with the first design phase of the project and the issues raised would be passed on to later stages for review, incorporation and further improvement.

One possible use of the final phase output might be to clarify risks which could not be designed out and which need to be taken into account for the construction, maintenance, operations and decommissioning phases of the project.

Hence, the report should fully document the following:

- the safety impacts that may have either arisen or been modified as a result of the design
- how those safety impacts have been addressed and mitigated in the design
- at detail design stage, identify issues that could not be designed out in the detail design which have been/should be incorporated in the specification for construction
- at detail design stage and potentially at the end of construction, identify issues that could not be designed out in the detail design and that have arisen during the construction which have been/should be incorporated in the specification for maintenance, operation and decommissioning activities of the project.

Procedure

Responsibility for actions and authorities for approval will be road agency and consultant-dependent. Typical responsibilities are:

- prepare generic lists of issues to assist with consistency
- identify target groups for the particular project, including any need for experts
- formulate the team
- workshop the generic issues and identify any additional project-specific safety issues
- consider options and evaluate them
- prepare a separate report where required by the client, the road agency or legislation
- include safety issues in the design report where a standalone report is not required
- approve report (if required), otherwise sign off on report and submit for client acceptance
- incorporate the outcomes in the design
- confirm the design changes have been made.

4.8.3 Constructability and Maintainability

Overview

The question for the designer is, ‘I am producing a design which conforms to other parts of the Austroads *Guide to Road Design*, but can it be built and can it be maintained?’

The question needs to be qualified further by adding ‘at reasonable cost to the community’.

As an example, it might be technically possible to remove hard rock in a cutting, but if that project is occurring in an isolated area and the cut volume is small, it might be prohibitively expensive to import the machinery/techniques to allow it to be completed, whereas a shift in the plan centreline or grade line may avoid the need for such a cut. Similarly, if the work is occurring in an urbanised area then blasting is most likely not an option and unless the rock can be ripped the design is flawed.

The process of checking for constructability and maintainability should be addressed at all phases of design and must, by its nature, be iterative during each phase.

For constructability, design decisions are linked to:

- the footprint available for construction work
- the design constraints for temporary works, for example, design speed and cross-section

- environmental constraints and need for temporary works
  - noise and noise walls
  - water and sediment traps
- the nature of the work
  - how it will be completed
  - specialist machinery, for example, tunnel boring equipment
  - what will happen to the excavated material?
- the expected staging of the work
  - contractor's access
  - when sections will be completed
  - earthworks and selected materials available at each stage
  - are the issues related to road design peculiar to that stage only temporary?
- the environmental conditions expected at the time of construction (noting that construction may be delayed and may extend over a number of seasons/years)
  - flooding of low-level sidetracks/detours
  - drought restricting the supply of water for compaction and dust suppression
- legislative requirements.

For maintainability, design decisions are linked to whether the future infrastructure can be:

- maintained
- maintained safely.

Some of the common issues that need to be thought about by the designer in terms of maintenance operations are:

- the footprint available for maintenance work and inspections
- the nature of the maintenance work – how it will be completed
  - what access is required for parking of vehicles and amenities?
  - how are drainage basins and gross pollutant traps to be cleaned?
  - how are bridge abutments and bridge structures such as box girders to be accessed?
- the expected frequency of the work
  - when repairs will be required
  - specialist machinery e.g. welding inside steel bridge girders, relining steel culverts
- the environmental conditions expected at the time of maintenance
  - flooding of low-level access tracks
  - water-affected unsealed access tracks
- legislative requirements, for example, confined spaces
- noise walls built against property boundaries – foundations necessitate clearance yet the resulting ‘strip’ is difficult to access
- retaining walls used in constrained sites to allow the desired cross-section to fit within the road reserve. Where the retaining wall is on the downhill side it is then difficult to access for maintenance.

Generally, on larger projects, these issues would be addressed by a team of relevant specialists that guides the development of the design, to ensure the best working knowledge of the circumstances surrounding construction and maintenance.

Some special considerations are discussed below.

Provision for traffic

It must be recognised that the safety of road users is dependent on appropriate design and therefore provision for traffic at all stages of the construction works must be fully designed in accordance with the relevant parts of the Austroads Guide to Road Design and road agency requirements.

Situations that will require design include:

- sidetracks and detours
- the existing carriageway where construction work has narrowed the available cross-section
- work on the existing carriageway.

Sidetracks and detours

These situations should be treated as full road designs utilising all the requirements of this part of the guide. Inputs will be required, although they may, because of the shorter design life, be reduced relative to the final design. Some of the inputs required will be design speed, capacity, cross-section, recurrence interval for drainage and a pavement design (note that the pavement design should provide a surfacing with adequate friction supply). The design should be done in accordance with the other parts of the Austroads *Guide to Road Design* and with road agency requirements.

Existing carriageway with narrowed cross-section

This category would cover situations where lanes are proposed to be reduced in number or narrowed in width, deviated or where shoulder widths or widths to identified hazards are to be reduced.

The provisions for sidetracks and detours should be applied.

It is worth noting that road agencies may have lane occupancy rules which set minimum design speeds where existing roadways are affected.

Work on the existing carriageway

Situations within this category would include short-term works such as daily lane closures.

It is worth noting that road agencies may have lane occupancy rules which set minimum design speeds and occupancy times where existing roadways are affected.

General

As a guide, some specific issues that might be considered in this context include:

- Is there enough width to provide for barriers to ensure safety for road users in the vicinity of excavations?
- Is there enough width to provide for signposting, delineation and other devices required for adequate provision for traffic
- Can power be provided for temporary traffic signals?
- Have flooding considerations on low-level detours for bridge repairs/replacement been considered?

- Does the existing or provided surfacing provide for the required friction supply?
- Can the site be accessed by trucks and plant/equipment?

It is important that legislative requirements be taken into account and that relevant agencies are contacted to establish local rules.

Requirements for worker safety

(See also Section 4.8.2).

As a guide, some issues that might be considered in this context include:

- Is there enough width to allow for installation of a safety barrier with an appropriate capacity (for example temporary concrete barriers have a physical width of 600 mm)?
- Is there enough width to allow for operation of a safety barrier required for workplace health and safety (for example dynamic deflection)?
- Is there enough length to enable the required development length for the anticipated barrier to enable it to function as designed?
- Are the access points to the site safe for workers to use, and do they provide enough protection for workers within the site?

Provision for workers should be considered at all stages of the construction works and should be accommodated in the design. It is important that legislative requirements be taken into account and that relevant agencies are contacted to establish local rules.

Temporary works

(See A.2.3).

Temporary interface

(See A.2.6).

As the work is, by definition, incomplete during the building phase, aspects of the design may not function correctly in isolation. Examples might be:

- If a bridge is completed before the approach roadworks, how should the considerable amount of water that may be directed into captured drainage be handled?
- Pavement layers should be overlapped, hence at the end of a section of work, full-depth construction is generally not allowed and hence is unavailable for trafficking.
- Because temporary linemarking is difficult to remove, the final wearing course is typically delayed until the project (or section) is nearing completion. If kerbs are present, then water is not able to access the gutter (being below finished surface level) and hence water is not directed into pits.

The work is generally staged; therefore, aspects of the design may not be readily corrected if problems are found. An example might be where legislation or project approvals may require that environmental controls are installed early (for example noise walls) but these are substantial structures/foundations, and this may interfere with the laying back of batters should erodible or surplus material be encountered.

Interfaces should be designed to operate through the various stages of construction.

Construction tolerances

Typically, the electronic design models in use work to sub-millimetre accuracy but generally round to the nearest millimetre. Designers need to understand that the work will not be constructed to this level of accuracy and that this may introduce issues otherwise not foreseen. Construction tolerances may vary with the road agency but typically range from 5 mm to 20 mm depending on the lot being considered.

Examples of these issues might include:

- ability to shed surface water and hence potential for aquaplaning
- ability to drain water into pits and channels
- ability to locate rigid safety barriers so that they generate sufficient friction to operate.

Procedure

Generic procedures and checklists may be useful to a design organisation to ensure that common constructability issues are accounted for in the design.

However, every design is unique; hence, the following procedure may allow for single use and assist with the identification of unusual or special features:

- Identify team members to provide constructability input.
- Identify environmental constraints and hence order of construction activities.
- Identify temporary works and areas required.
- Identify constraints to access such as bridges, major culverts, steep slopes and large cuts.
- Identify likely earthworks movement and methods.
- Propose staging.
- Identify traffic control together with access points.
- Identify worker safety requirements e.g. clearances or otherwise required safety barrier types.
- Identify required temporary cross-section – input to design.
- Identify temporary input to design.
- Identify materials storage areas e.g. topsoil stockpiles – input to design.

5. The Road Design Process

5.1 General

The road design process encompasses a range in project size and complexity from small projects (minor improvements, intersection upgrade) to major projects (network expansion, 'greenfields' work on major arterials and freeways).

Depending on the size and complexity of the project, a number of design phases may be required. These phases form a continuum and generally begin by examining options to establish a preferred solution and developing it to a level that will give confidence to the client and finally detail the design. The names given to these phases vary between road agencies and it is, therefore, necessary to refer to local jurisdictions for local terminology and specific requirements.

Planning and design are each iterative processes, requiring assumptions to be made using the available data. As the project proceeds and more data become available, the validity of the assumptions needs to be checked and necessary modifications made. Essential to the planning process are road designs that are accurate enough to demonstrate the feasibility of various options and to confidently define right-of-way requirements. Design is a product and the systems that are put in place should conform to the model for Quality management systems – requirements, set out in AS/NZS ISO 9001:2016.

It should be noted that while compliance with standards and this guideline should ensure an acceptable design, it does not necessarily ensure ‘good design’. Good design is achieved when the outcome not only conforms with but exceeds expectations. Designers should be encouraged to explore a number of solutions so that the outcome is the best available balance within the project constraints.

The design should be tailored to meet the needs of current and future generations through the integration of many factors which might generally be described as including user safety, workplace safety, environmental protection, social advancement and economic prosperity. This may require challenging the limits originally set for the project.

The design process can be summarised in the following elements:

- planning and developing the processes required to realise the design
- determining the requirements for the design
- reviewing the requirements for the design
- determining the arrangements for communicating with the client
- controlling the design in stages and determining the appropriate reviews and authorities
- determining the controls that will apply to the interfaces between design stages
- determining what inputs are required
- determining what outputs of the design process are required and in what form
- reviewing the design at suitable stages in its development
- verifying that the design outputs have met the input requirements
- validating the project outcome to ensure that it is capable of meeting the intended use
- controlling any design changes
- undertaking a quality system audit
- controlling the presentation of outputs
- developing procedures to manage design exceptions

Additional information regarding design development and the phases of design are detailed in Appendix A.

5.2 Design Report

Throughout the phases of design, a ‘live’ document in the form of a Design Report provides a summary of existing conditions, design objectives, assumptions, constraints, design methodology, safety in design, safe system principles and details of any elements using EDD or DE. The designer commences preparation of the report at the start of the project and the report is reviewed and evolves through each phase of the design. The report content should reflect project risk level at the stage of design that is complete.

Users should check the requirements for the particular project and/or jurisdictional requirements to determine the extent of reporting required.

5.2.1 Design Report Content

The following provides an extensive list of content to be considered in a design report. Depending on the size and complexity of a project, individual reports may be required for each technical discipline during each phase of a project. Practitioners should liaise with jurisdictions regarding the extent of reporting required.

Document management

- amendment records
- distribution list
- document ownership and use
- document status e.g. revision number, author, reviewer and approval for use
- the author’s company contact details
- file and project numbers.

Project background and purpose

- project name
- location
- design report phase e.g. concept, preliminary, final or per cent complete
- project number or contract number
- document status e.g. draft, final
- project description and context
- definition of the problem(s) and existing conditions
- guides and standards used to inform the design
- existing constraints e.g. physical, heritage, environmental, services
- details of hold points where relevant
- reference design
- stakeholders.

Design objectives

- key functionality targets e.g. design year(s), network productivity/performance, safety, movement and place
- key design criteria adopted e.g.
  - design, posted, operating speeds
  - design vehicle (design and check vehicles)
  - sight distance
  - cross-section
  - road reserve
  - roadside design i.e. hazard mitigation
  - safety barriers
  - reaction time adopted
  - batter slopes (cut and fill)
  - drainage flow paths
  - design ARI
  - horizontal alignment elements e.g. curve radius, taper lengths
  - vertical alignment elements e.g. longitudinal grade, minimum crest curve K
  - provision for pedestrians and cyclists e.g. on-road, shared path
  - heavy vehicle routes e.g. PBS, higher mass, over dimension
  - lighting standard
  - traffic signals and ducting
  - property access
  - emergency access
  - drainage
  - noise barriers/walls
  - land acquisition/clearances/special accesses
  - utility services and relocations
  - structures e.g. bridges, culverts
  - construction issues
  - geotechnical
  - ITS
  - public transport e.g. indented bus bays
  - urban design objectives
- works and temporary works
- safety in design
- design life of infrastructure elements
- asset maintenance practices (whole-of-life)
- pavement design and rehabilitation strategy.

Design controls assumed

- clearances
- clearance envelopes including clearances to existing and new structures
- structural depth assumptions
- drainage outlet controls (including Water Sensitive Urban Design)
- base survey accuracy
- traffic forecasts.

Document design criteria used

- key design criteria adopted from guides and standards
- design risks that have not been addressed in the design package submitted
- directions given by client during design, document level of approval
- options considered during the design that were not progressed (and why) including technical analysis highlighting advantages/disadvantages of each option
- calculations.

Documentation and approvals

- turning movements – turning vehicle swept path diagrams, including vehicle type adopted
- sight lines – provide sketches/diagrams which display sight lines, including vehicle type and what type of sight distance has been achieved
- truck stability analyses
- evidence of any required approvals e.g. traffic controls, electrical
- inclusion of required checklists e.g. presentation, electrical design
- summary of actions from road safety audits and Safe System assessments
- design verification
- independent design certification.

Non-conforming design elements

- document design criteria used but not included in guides and standards (i.e. any criteria established for innovative solutions)
- summary of approved EDD criteria adopted in the design, including clear descriptions of the capability provided in the solution with respect to the design guide and any mitigation measures proposed
- summary of approved design exceptions adopted in the design, including clear descriptions of the capability provided in the solution with respect to the design guide and any mitigation measures proposed.

Appendix (depending on project scope)

- ramp meter (road management system) – table outlining required and achieved storage
- signage requirements
- existing structural assessments
- geotechnical information

- land acquisition
- community consultation
- construction staging plans

The design report can be presented in tabular form, listing all the parameters considered, and the values adopted for each of those. An example is shown in Table 5.1.

Table 5.1: Road design standards adopted for the project (Stage 1 and Ultimate)

Road B/Road A/Kwinana Freeway Link	
Carriageway lane widths	Refer Typ. Cross-section Dwg's at Appendices A & B
Auxiliary lane widths	3.5 m
Shoulders – left	2.5 m wide, 1.5 m sealed
Shoulders – right (typical median)	1.0 wide, 1.0 m sealed
Shoulders – right (next to northbound rail)	2.5 m wide, 2.5 m sealed
Median	Nominally 31.0 m (varies)
Crossfall	3%
Superelevation	5% maximum
Grades	Unkerbed: 3% maximum, 0% minimum. Kerbed: 0.3% minimum
Batters	1 in 1.5 maximum, bridge abutments 1 in 6 typical, table drain Cut/Fill: 1 in 3 typical, interface
Ramps (Kerbed)	
Crossfall	3%
Superelevation	6% maximum
Grades	6% maximum, 0.3% minimum
Verges	2.0 m wide minimum, 2% typical
Batters	Cut/Fill: 1 in 3 typical, interface
Single lane ramp	
Carriageway lane width	1 lane 4.2 m wide >
Shoulder - left	2.8 m wide, 2.8 m sealed
Two Lane Ramp	
Carriageway lane widths	2 lanes, 3.5 m wide each
Shoulders	None
Side Roads	
Carriageway (dual with median) lane widths	2 lanes each way, 3.5 m wide each
Carriageway (single) lane widths	2 lanes, 3.5 m wide each
Shoulders (dual carriageway with median)	Outside: 2.5 m wide, 1.5 m sealed Median: 1.0 m wide, 1.0 m sealed
Shoulders (single carriageway)	2.5 m wide, 1.0 m sealed
Crossfall	3%
Superelevation	5% maximum
Grades	6% maximum, 0.3% minimum
Verges	2.0 m wide minimum, 2% typical
Batters	1 in 3 typical

Road B/Road A/Kwinana Freeway Link	
Design Speed **/Posted* Speed	
Road B	80 km/h/70 km/h
Fremantle Road/Centennial Park Estate	60 km/h/50 km/h
Meadow Springs Access Road (Cha 2500)	50 km/h/50 km/h
Road A	90 km/h/80 km/h
Kwinana Freeway Link	90 km/h/80 km/h
Meadow Springs/Waste Transfer Station Access	40 km/h/40 km/h
Gordon Road	70 km/h (low speed environment)*/60 km/h*
Ramps (standard)	70 km/h/60 km/h
Ramps (parclo)	40 km/h/40 km/h
Exchequer Road/Fremantle Road	70 km/h/60 km/h
Pavement Design	
Road B/Road A/Kwinana Freeway Link	
Pavement depth	350 mm
Basecourse layer	100 mm
Sub-base layer	250 mm
Side roads	
Pavement depth	250 mm
Basecourse layer	100 mm
Sub-base layer	150 mm
Design Vehicles (Intersections)	
Fremantle Road/Centennial Park Estate	Semi-Trailer
Meadow Springs Access Road (Cha 2500)	Semi-Trailer
Kwinana Freeway Link	B-Double
Meadow Springs/Waste Transfer Station Access	Semi-Trailer
Gordon Road Interchange	B-Double
Exchequer Road/Fremantle Road	B-Double

** The proposed design speed for Road A was originally 110 km/hr. (Main Roads Design Brief Section 2.12). However, this design speed could not be achieved due to the constraints of the PRS road corridor, especially at Gordon Road Interchange, and the requirement for signalised intersections.*

Source: WA Main Roads.

It is important to note any deviations from the normal design domain, including design exceptions and use of the extended design domain, and to ensure that adequate justification and supporting evidence for the adoption of the deviations is recorded, as well as any required approvals.

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NZS 4407:2015, *Methods of sampling and testing road aggregates*.

Appendix A Process and Documentation

Process and documentation are the means by which designs are produced in an efficient manner, and which ensure that all factors that should influence the desired outcome are taken into account. Documentation enables the decision-making process to be retraced, if necessary and is the basis for quality management. This Appendix describes requirements for quality of documentation and presentation.

A.1 Preparation for Design

A.1.1 Overview

A design control process should apply throughout all stages of a design project and should include the following activities:

- preparation for design (Appendix A.1)
- design development (Appendix A.2)
- design review, verification and validation (Appendix A.3)
- design process and quality system audit (Appendix A.4).

The design control process should be planned and clearly shown on a design program, with appropriate resources and time allocated to complete the activities. The hold points for design control should be specified in the quality plan for the project.

A.1.2 Design Control Process – the Relationship to ISO 9001

The design processes followed and required by a road agency (for any design phase described in Section 4.2) generally follow the requirements of ISO 9001 (Clause 7). The standard was written in terms of 'product', and for the purposes of this part, and the Guide to Road Design in general, the use of the term 'product' will be limited to the design documentation produced at the end of any design phase.

The design processes and its relationship with ISO 9001 can be summarised as follows:

- Planning and developing the processes required to realise the design (Appendix A.2). This is a subset of the requirements for the project management processes which are described in the *Guide to Project Delivery Part 2: Project Delivery Planning and Control* (Austroads 2019h) (ISO 9001 Cl 7.1).
- Determining the requirements for the design (Appendix A.1.5) (ISO 9001 Cl 7.2.1).
- Reviewing the requirements for the design (Appendix A.1.5) (ISO 9001 Cl 7.2.2).
- Determining the arrangements for communicating with the client (Appendix A.1.4) (ISO 9001 Cl 7.2.3).
- Controlling the design in stages and determining the appropriate reviews and authorities (Appendix A.2 and A.3.3) (ISO 9001 Cl 7.3.1).
- Determining the controls that will apply to the interfaces between design stages (Appendix A.3.5) (ISO 9001 Cl 7.3.1).
- Determining what inputs are required (Appendix A.1.6) (ISO 9001 Cl 7.3.2).
- Determining what outputs of the design process are required and in what form (Appendix A.1.7) (ISO 9001 Cl 7.3.2).
- Reviewing the design at suitable stages in its development (Appendix A.1.5) (ISO 9001 Cl 7.3.4).
- Verifying that the design outputs have met the input requirements (Appendix A.3.9) (ISO 9001 Cl 7.3.5).
- Validating the project outcome to ensure that it is capable of meeting the intended use (Appendix A.3.10) (ISO 9001 Cl 7.3.6).
- Controlling any design changes (Appendix A.3.6, A.3.7 and A.3.8) (ISO 9001 Cl 7.3.7).

- Undertaking a quality system audit (Appendix A.4) (ISO 9001 Cl 8.2.2).
- Controlling the presentation of outputs (Appendix A.5).
- Developing procedures to manage design exceptions (Appendix A.3.7).

A.1.3 Use of Design Control Aids

Aids in the form of standard lists of items to be considered for design can provide prompts for each stage of the design control process. However, they are not a substitute for design knowledge, experience and judgement.

These should be reviewed prior to adoption against the project parameters and complexity. Where necessary, further items should be added to the list for completeness.

The list of items might be contained within a tabular format which, when completed, will provide a record that the stages of design have been carried out, the date of the check, and follow-up action which may be required.

A.1.4 Client and Designer Interaction

Overview

(See also Clause 7.1 of ISO 9001).

While road projects are delivered by different agencies (both public and private) and those agencies will have different organisational structures and hence different titles, roles and authorities, the delivery of infrastructure projects whether large or small will generally have a separation of roles between:

- the project initiator, often titled the ‘client’ or the ‘asset owner’
- the project deliverer, often titled the ‘project manager’
- the designer.

The descriptors used within this appendix are client, project manager and designer.

The client for road projects is usually considered to be the organisation that has ownership (‘care and control’) of the ultimate asset. As the asset owner the client has the responsibility to ensure that a brief is prepared detailing requirements. Minimum requirements are:

- operational outcomes required to be delivered by the project
- the design criteria to be satisfied (pavement design life, average recurrence interval for drainage design, etc.).

The role of the project manager is to deliver the project in accordance with the client’s brief and conditions of contract. This role is covered in detail in other Austroads publications, in particular those within the area of project delivery.(Austroads Guide to Project Delivery series AGPD-19) Effective and efficient project management, together with regular client involvement, will greatly contribute to a smooth process that delivers the ‘right’ project with minimal rework. The project manager can assist with the design process by managing the timely acquisition and integration of:

- a project team with all of the necessary skills and experience
- all project-related procurements
- all project-related communications
- regular risk identification and management.

The designer is responsible for design management and design development activities that ensure a good design, not just merely complying with standards and processes. To achieve this it is absolutely critical that the designers are appropriately qualified and experienced.

The relationship between the roles may differ within road agencies and often depends on the procurement method used for the project overall and the design delivery in particular. The method used for design delivery is most often outside the control of the designer. The designer should realise that the choice of procurement method is influenced by assessed critical project risks, of which technical risk may or may not be one. Thus the procurement method may not facilitate the design process.

A collaborative approach that involves the client and project manager in the design of road infrastructure projects will assist with making the project delivery a smooth and efficient process and can enhance the quality and effectiveness of the project outcome.

Client and project manager involvement

It is desirable to have the client and project manager involved in the design decision-making process on a regular basis. The frequency of project design meetings should be such that the client is able to have the necessary regular input into the design decision-making process and also to approve solutions as they evolve.

This process should contribute to:

- the design better meeting the functional requirements of the client
- reduced rework
- improved quality of decisions
- improved efficiencies
- better working relationships.

For the designer, gaining client and project management leadership is more than just having them involved; it is about actively modelling the way forward to achieve the desired state through strong influencing and collaboration progressively addressing risk throughout the whole process.

Relations management

The management of relations with other parties or bodies necessary to complete the design process is critical. It requires establishing and maintaining good relationships from the start-up meeting. Whether the process is formalised or not, it relies on all parties to develop and maintain good relationships to ensure optimum outcomes for the client, the project manager, the designer and other interested parties including the constructor and the community by aligning the efforts of the parties and making best use of the expertise and resources available. Ultimately, it is targeted at delivering the best possible project outcome.

A.1.5 Scope of the Design

The design brief

The design brief should clearly articulate the client’s requirements (refer also to Cl 7.2.1 of ISO 9001).

The design brief fulfils a number of functions:

- contractual
  - as a minimum, it generally forms the basis for the technical specification within the agreement between the parties
  - defines the design phase(s) required and hence the approach that the designer will take to each level of detail
  - defines the scope of the design work (what is not required is often important) and hence the level of design resource and expertise that needs to be applied

  - provides information about the objectives of the project and the functionality required including the period of use, future change in use and future upgrades
  - provides detail about the quality system requirements under which the designer will work
- technical
  - – provides details about the nature and volume of inputs
  - provides details about the nature and volume of outputs.

The designer should review the brief for accuracy and completeness. Matters related to the review are dealt with in the remaining parts of this Appendix.

Review of requirements specified in the design brief

(See also Clause 7.2.2 of ISO 9001).

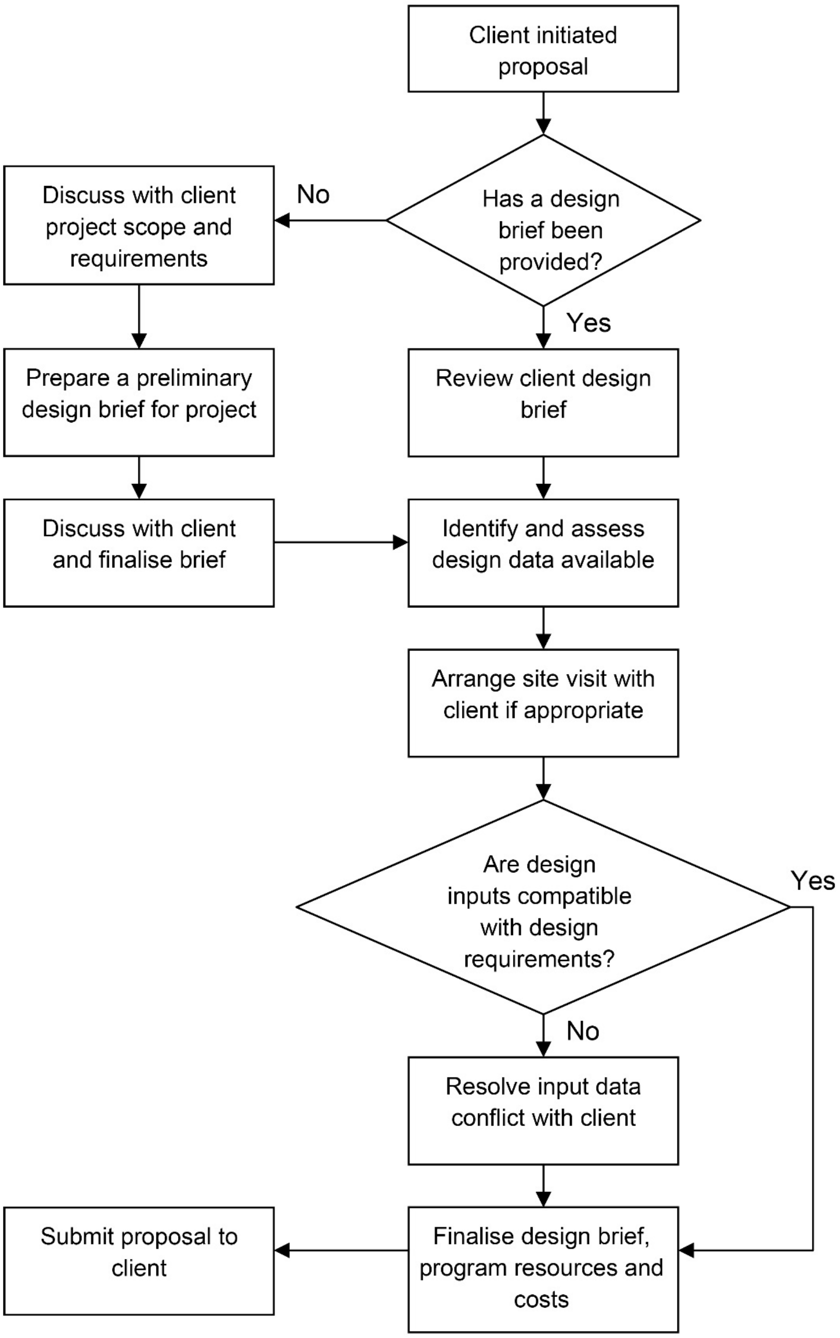
The purpose of the design brief review is to ensure that the client's project requirements are understood so that informed decisions can be made on the type and level of service to be provided and adequately reflected in the development of a design proposal which would cover areas such as design standards, principles to be applied, program of works and costs of the project.

The objective of the contract review is to establish:

- the relationship with the client addressing contractual arrangements, decision-making, risk sharing, time frame, budgetary controls, and design variation controls
- the type and level of resources required including skill, knowledge, and technology requirements
- the project requirements including the scope of work
- inputs including design standards, principles, statutory and regulatory requirements, and project performance criteria (for further guidance see Appendix A.1.6)
- the adequacy of the design information/data against the project performance requirements including constructability, safety and operational maintenance (for further guidance see Appendix A.1.6)
- the level of design output required (for further information see Appendix A.1.7).

Figure A 1 illustrates a process for carrying out a review of the design brief. Designer input is desirable and is often necessary in the preparation of a design brief.

Figure A 1: Review of the design brief



Source: Adapted from VicRoads (1995).

Appropriate documentation should include decisions and the reasons for them and will, as a minimum, consist of the design report, specifications and model/standard drawings.

The important aspects of this process that should be addressed are:

- communication with the client to determine project requirements and resolve differences in order to reach an agreed understanding
- review of the specified technical requirements for appropriateness
- review of available design data for compatibility with project requirements and the identification and accessibility of additional data needs.

Apart from quality records, significant outputs from the review process would include a design program that clearly shows the appropriate resources and time allocations for design activities including design control and an estimate of project design cost.

Guidance for contract review

The items that may be considered for checking in the contract review process include:

- the scope and extent of the required work
- the availability of relevant reports (project concept, environmental impact statement (EIS), materials investigation, design status, traffic engineering and safety review)
- availability of design data files (geospatial, design, drawing, cell libraries and utility services)
- the specification of design criteria (design guides, reference materials and standards adopted)
- environmental studies (cultural heritage, site surveys, flora and fauna surveys, noise studies and community issues)
- community consultation requirements
- municipal and planning authority requirements (environmental controls, conservation areas, historical buildings planning permits, planning scheme classification)
- right-of-way concerns/controls
- project staging requirements
- project control requirements (hold points, design reviews, road safety audit, proof engineering)
- responsibility for services information (contacting authorities and obtaining approvals)
- responsibility for decision-making
- list of project contact officers
- nomination of project superintendent and quality representative
- process for design variations approval
- scope for variation of design concept
- type of after service to be provided
- type of documentation required
- presentation of design
- project time frame
- budgetary constraints
- type of contract (limiting fee, lump sum, schedule of rates, fees for additional work, progress payment – see also Section 4.8)
- contract conditions (security deposit, retention money, liquidated damages, insurances).

A.1.6 Design Development Inputs

Purpose

The design inputs review phase should identify the information to be used as the basis of the design or to be incorporated into part of the design. It should assess the adequacy (both quality and quantity) of the information against the project objectives and performance requirements.

Classification of inputs

Information that must be used as inputs to the design process may be categorised into two broad areas:

- criteria/rules/protocols
- data.

Criteria/rules/protocols

Design inputs that might be classified as criteria, rules or protocols include:

- performance and functional requirements
- design principles
- project specification
- design standards and codes
- statutory and regulatory requirements
- services authorities specifications
- environmental conditions of approval
- other agency requirements
- minutes of meetings.

It should be noted that different rules and protocols will apply to different design packages if those packages are established on a discipline basis, for example, road and bridge design, but they may also differ within a discipline, for example, design for 'through' as opposed to 'local' road design within the same project.

Data

Design inputs that might be classified as data include:

- survey information including metadata
- drawings and other design output from the previous design phase
- site inspection reports
- traffic surveys
- road safety audit reports
- geotechnical reports
- environmental reports
- community consultation.

Typically, input data is provided on a project basis with the designer for each package selecting the data required for its design process.

Guidance on areas of potential impact

The following listing of technical subject areas may include information that designers need to take into account during the design development process. It is not exhaustive and is included for guidance only:

- Austroads guides
- Australian and New Zealand standards (AS/NZS)
- safe design legislation/management requirements
- engineering policy
- environmental legislation/management policy
- influences of climate, for example roads in the wet tropics
- timber bridge maintenance
- risk management guidelines
- traffic and road use management
- management of roadside advertising
- assessment of road impacts of development
- asset maintenance guidelines
- project management/delivery systems
- contract administration system
- cost estimating
- cost sharing arrangements
- drafting and design presentation standards
- surveying standards
- model/standard drawings for roads
- standard specifications for roads
- standard specifications for Intelligent Transport Systems (ITS) and electrical technology
- urban design/landscape design
- fauna-sensitive road design
- road traffic noise management
- air quality management
- construction noise and vibration management
- heritage
- materials testing
- pavement design
- pavement markings
- uniform traffic control devices
- design for roadside signs
- sign-face design
- street/roadway lighting
- product approvals including safety barriers
- traffic control at worksites.

Process

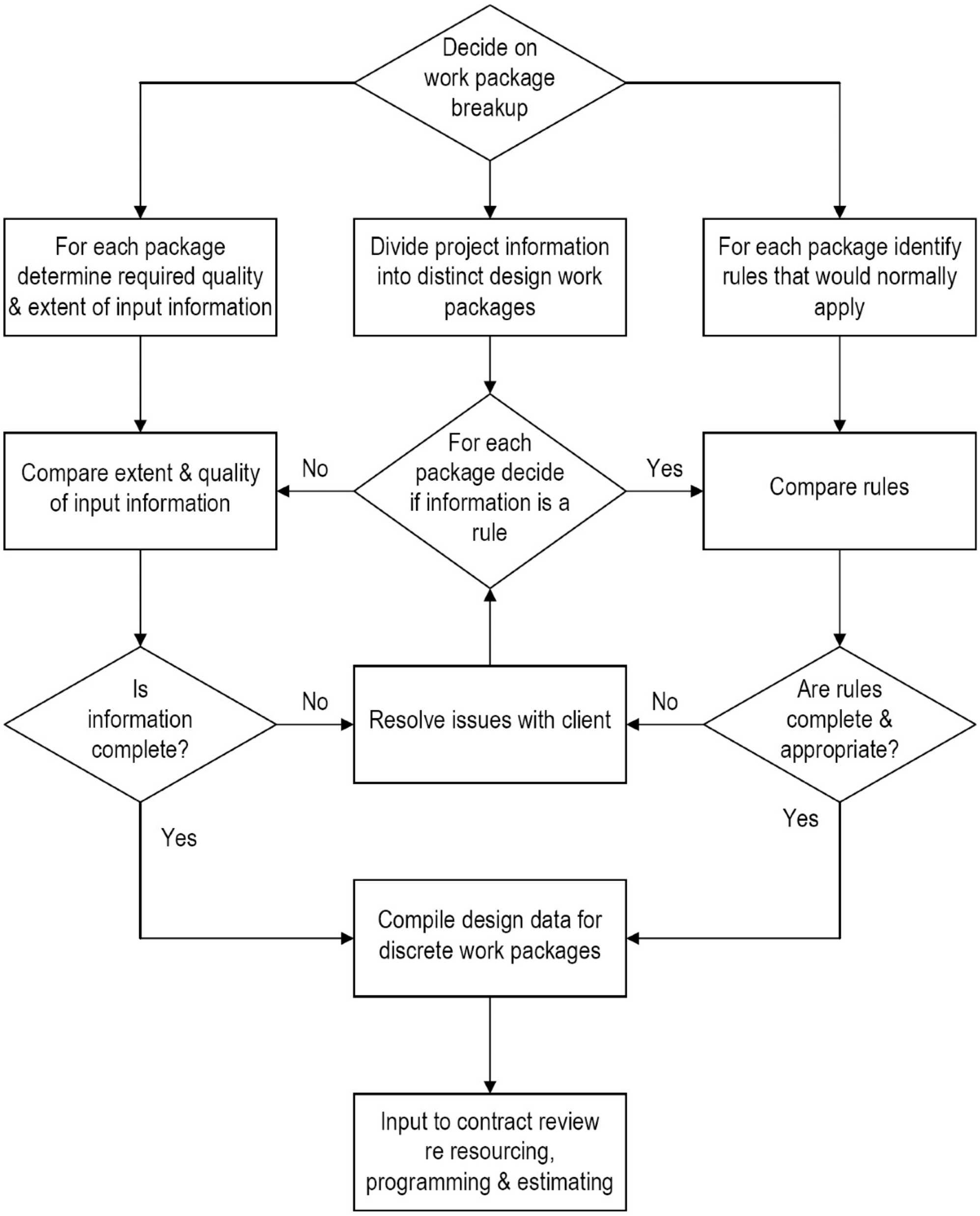
The process used in the design input information review would generally include the following steps:

Break the work into packages. Typically, packages are in the first instance selected on the basis of design discipline, for example road, bridge, geotechnical, pavements, urban design and landscaping. These may then be broken down further (Appendix A.2.6).

- For each package:
  - identify whether the information is a rule (or protocol) or input data
  - for rules and protocols
    - identify the design information requirements
    - compare the supplied rules (or protocols) with the designers reference list
    - resolve any omissions or discrepancies or ambiguity in the rules supplied by the client
  - for input information
    - identify the design information requirements
    - determine what information should be made available
    - resolve any shortfall, discrepancies or ambiguity in the information supplied by the client or obtained by the project team.

Figure A 2 illustrates the process for design input information correlation and review.

Figure A 2: Design input checking process



Road safety audits

A road safety audit can provide information that can be used by the road designer either as one of a number of initial inputs to the design process or as a part of the review process for a design (for further discussion on the review aspect see Appendix A.3.4).

When it is supplied as an initial input to the design process, it is a formal examination of either:

- a design output from a previous design phase
- an existing road.

The examination is one in which an independent, qualified team skilled in the areas of crash prevention and road safety engineering, reports on the project's crash potential and expected safety performance.

A road safety audit has potential for improving safety and should be done both before and at appropriate stages in the design development.

There are four opportunities within the design development process for a road or traffic project when a road safety audit on a design should be conducted, regardless of the size or nature of the project:

- Feasibility Stage Audit: When establishing a preferred solution (Section 4.2.1)
- Preliminary Stage Audit: once the preferred solution has been developed (Section 4.2.2)
- Detailed Design Stage Audit: once the detailed design is complete (Section 4.2.3)
- Pre-opening Stage Audit: at the pre-opening stage (or soon after the project is complete).

For 'restoration' type projects, an existing road audit together with a road geometric assessment will form the basis to determine if the road will be made better or will become less safe by the proposed design. A road proposal that makes the road less safe cannot be accepted.

A road safety audit can be utilised to provide information outside those opportunities specified above. It can be conducted on any design proposal that involves changes to the ways road users will interact, either with each other or with their physical environment.

As a matter of good practice and as part of a quality management approach, the designer should make regular, informal checks of the physical safety of a design as it progresses. Road safety audits do not alter the need for this safety-first approach amongst designers. When a road safety audit is conducted, it should be noted that it provides information either as an initial input or as a part of the review process, and as such it is considered by the designer and/or by others as appropriate (typically the project manager or the client) along with all other information in the design process. The client or the project manager are usually accountable for closing out matters raised in the safety audit.

It should be noted that some road agencies restrict the audit report to findings only.

Further considerations

Further items to be considered for the correlation and review of the design inputs information include:

- council controls and approvals
- concept reports and approvals
- environmental reports and approvals
- planning scheme details (row definition, clearances, land acquisition)
- access control
- associated designs including bridge, geotechnical, pavement, drainage
- ultimate capacity strategy
- road geometry controls (operating speed, minimum radii, maximum grade, minimum grade)
- cross-section details (traffic lane width, median width, shoulder width, verge width, table drain, batter slope, benching requirements)
- traffic analysis details (traffic volumes, traffic composition, turning volumes, crash numbers/types)
- design vehicles
- desired level of service
- turning movements to be catered for (types of movement, volume of traffic, number of turning lanes, types of vehicle)
- dimensions and clearances to structures, services, and major features
- other features such as rest areas, truck stops, breakdown bays, telephones, lighting, ITS
- service relocation strategy (water supply, sewerage, drainage, telephone, gas, electricity, other)

- critical physical control areas (locations, horizontal, vertical, reduced levels)
- overtaking requirements or provisions (location, length, merge taper, diverge taper)
- geographical information
- geotechnical reports and approvals (pavement details, stratum levels, rock, watertable levels, underground mining shafts both current and disused)
- drainage details (controlling authority, control levels, flood levels, drainage strategy approval, approval to use major outfall)
- existing drainage network details (outfall locations, flood prone areas, existing network drainage strategy, local history)
- bicycle and pedestrian facility requirements and provision for special users
- bridge approvals (structural depth, site plan, general arrangement)
- pavement details (type, depth)
- construction staging strategy (location of temporary connections, re-sheet and overlay requirements, excavation staging, traffic control measures, maintenance access) and constructability
- engineering risk reviews
- landscape and urban design provision (land forming locations and requirements, special features to be preserved/protected, special features to be constructed)
- urban design requirements
- noise attenuation strategy (location of noise mounds, location and type of noise walls)
- existing road maintenance problem areas that require consideration
- authorities including federal, state and local government, utility providers, public transport providers (road, rail and air)
- local underground and above-ground services
- engineering survey
- cadastral survey
- hydrology of major waterways
- native title
- airport/shipping port requirements
- special vehicle route requirements
- enforcement site requirements.

The importance of an onsite review of the emerging design cannot be overstated. The designer (and concerned others) should visit the site to ensure that the planned solution will fit appropriately with the existing and proposed circumstances. It is suggested that an early visit with the client and/or project manager will give confidence to all parties that the proposed design is likely to successfully meet the client's expectations. Subsequent visit(s) can be used to confirm, for example, that detailed geometric and drainage solutions will be fit-for-purpose prior to finalisation of design and documentation.

Documentation

The completed checking aid provides a summary of the depth of the design inputs review. Supportive evidence of the satisfactory completeness of the process needs to be maintained and would generally include:

- minutes of meetings and/or discussions, with specific reference to agreed actions
- correspondence seeking clarification or requests for information
- program of works
- calculations and analysis of data.

A.1.7 Design Development Output

ISO 9001 (Clause 7.3.3) sets out a number of requirements for the design output and these are summarised below so that the outputs should:

- meet the input requirements (see also Appendix A.3.9)
- provide appropriate information for purchasing
- contain or reference acceptance criteria
- specify the characteristics of the product that are essential for its safe and proper use.

Thus for road design, the output from the design process typically includes:

- hard copy drawing(s) and/or a project electronic model
- the design report
- specifications and other documents required to purchase and build the project
- quality system records.

The first three components are generally described as ‘design documentation’ and would be provided for the construction of the product.

The fourth output, together with the other three, is used for verification and as a formal record.

A.2 Design Development

A.2.1 Overview

As stated in Appendix A.1.1, the design processes required by a road agency (for any design phase described in Section 4.2) generally follow the requirements of ISO 9001 (Clause 7).

The processes are set out in full in Appendix A.1.1 but those relating strictly to the production of the design are repeated here:

- planning and developing the processes required to realise the design (A.2.2) (ISO 9001 Cl 7.1)
- controlling the design in stages (A.2.4) (ISO 9001 Cl 7.3.1)
- determining the controls that will apply to the interfaces between design stages (Appendix A.3.5) (ISO 9001 Cl 7.3.1)
- controlling any design changes (Appendix A.3.6, A.3.7 and A.3.8) (ISO 9001 Cl 7.3.7)
- controlling the presentation of outputs (Appendix A.5)
- developing procedures to manage design exceptions (Appendix A.3.7).

Develop the design in accordance with Parts 1 to 7 of the Austroads *Guide to Road Design*.

A.2.2 Producing the Road Design

Planning

Planning and developing the processes required to realise the design are a fundamental requirement.

When applied to a project design, the output from this initial process is the design management plan, which will control all future design activities for the project.

Considering output from previous phases

Design output from a previous phase will generally provide direction and (depending on the contract arrangements) will control design endeavours in this phase.

Considering previously prepared designs

Previous designs may have been undertaken by another designer and may be fully or partially complete. Considering these designs may give guidance and (depending on the contract arrangements) may control design endeavours for this phase.

Obtain any additional information

The review of design inputs is covered in Appendix A.1.6 and includes a list of typical inputs. That, together with the factors noted in Appendix A.2.2 will determine whether additional input data is required.

Stage(s) of completion

The design is to be controlled in stages (ISO 9001 Cl 7.3.1). The term ‘stage’ in ISO 9001 is a general one, and for use in road design it applies to:

- parts of the overall design including components and packages
- stage of completion.

This applies to all phases of design, although the degree of detail required will vary with the phase and the delivery method chosen (Section 4.8 and Appendix A.2.3).

Design components

Road design encompasses different components, which are performed by different groups generally based on discipline (Appendix A.2.6). For example, a road designer would design for road geometry while a geotechnical engineer would design for slope stability.

For each component, the development of the design should be done in such a way that:

- the overall design process is facilitated and separate components can be properly integrated
- the review process can add value to it.

The design management plan is used to control the design process.

In regard to review it is usual that there are at least three formal opportunities for this to occur and these opportunities are generally designated as ‘completion stages’.

Completion stages

Historically, a nominal percentage completion figure has been used to indicate the progress of the design development and trigger other processes including review and verification. The nominal percentage completion varies slightly between jurisdictions and two examples of these include:

- 20%, 80% and 100%
- 15%, 85% and 100%.

Depending on the scale of the project, the nature of the contract and jurisdictional requirements the preparation of Issued for Construction (IFC) documentation may be included in the final stage or may represent a separate stage.

The above values are generally viewed as being a percentage of overall completion. However, because of the linear nature of design, a completion stage may be associated with the completion of one or more of the activities of road design. Whilst those activities follow a sequence determined by the type of work, a typical sequence for activities and a grouping into stages follows:

- Stage 1: Initial – 15%
  - preparing the cross-section
  - determining the alignments
- Stage 2: Further development – 85%
  - intersection design
  - traffic signals
  - drainage
  - roadside furniture and delineation
  - construction staging and temporary works
- Stage 3: Final – 100%
  - all design documentation including reports, specifications, and model/standard drawings.

The required stages and their composition will be determined by the client.

It must be remembered that a design process is iterative and earlier activities may have to be revisited to ensure that all input requirements are met.

Some discussion on each of the activities follows.

Preparing the cross-section

Depending on the phase of design being considered, information such as the number and width of lanes, shoulder widths, kerb types etc., will be decided and will have constituted one of the inputs to the design (refer to Austroads 2016a).

Generally the cross-section for the work will include details for pavement layers and depths as well as nominal batter slopes (refer to the relevant parts of the Appendix B).

Determining the alignments

(With reference to Austroads 2016a).

Both the horizontal and vertical alignments will be determined and will be coordinated. The combination of alignment and cross-section will allow the designer to confirm that surface water is shed quickly off the road surface and that any potential for aquaplaning is adequately addressed.

A preliminary assessment of drainage should be undertaken to determine whether it will influence the proposed grade-line. A preliminary assessment of the need for bridges should also be undertaken to determine whether they will affect the horizontal or vertical alignment.

Setting the alignments and the cross-section will allow earthworks to be balanced or not, depending on requirements.

The alignments together with the cross-section will allow for a preliminary assessment of the location of the road boundary and hence the need for property adjustments or a change to batter slopes and, potentially, retaining walls. This may cause the alignments and the cross-section to be reconsidered.

Intersection design

(With reference to Austroads 2017a).

Intersections include those junctions with private accesses as well as other public roads.

The cross-section and the alignments will determine the aspects of those junctions such as whether they are in cut or fill, the approach grades, the amount of sight distance available and hence the lateral extent of the work. The alignments may need to be re-examined in light of these considerations.

Traffic signals

Traffic signals are typically required for intersections carrying larger traffic volumes, but they are not ‘passive’ in operation and require both power and communications at the site. It should be noted that some jurisdictions have limits on the speed zoning in the vicinity of the signals (refer to Austroads 2017a).

Traffic signals at larger intersections may require large posts and large foundations. These may require a reassessment of available space, especially with regard to underground services (refer to Austroads 2020a).

Drainage

(With reference to Austroads 2013b).

The term ‘drainage’ includes both drainage from the road and its environment as well as existing drainage lines. The required transverse drainage capacity together with the channel characteristics may influence the alignments. The alignments in turn will identify the slopes of drainage lines and hence the need for inlet and outlet controls. It should not be forgotten that such devices may have a significant footprint and this in turn will influence the setting of boundaries.

Roadside furniture and delineation

(With reference to Austroads 2020a).

The essence of a safe road design is one that encompasses passive safety. An example of passive safety is the use of flatter batters, rather than steeper ones which require safety barriers. The flattening of batters is something which should be considered early in the design development, because of its effect on earthwork balance, drainage and footprint.

Other potential hazards, such as signposting, should be assessed early so that an appropriate allowance in the cross-section can be made to accommodate deflection requirements for safety barriers.

Items such as noise barriers should be considered early because of their lateral space requirement, their functionality requirements such as height and their effect on drainage and maintenance access requirements. These may require a re-adjustment of alignments. The road geometry can also impact on the height of noise barriers.

Roadway lighting will have a lateral space requirement, will require power and may require communications and safety barriers.

The alignment will determine adjustments to public utilities and the utility design may, in turn, impact on cross-section and geometry requirements. In addition to utilities, the incorporation of Intelligent Transport Systems (ITS), not usually allowed for in utility space agreements, may therefore require an increase in cross-section.

Provision for cyclists and pedestrians may impact on cross-section requirements and intersection design.

Construction staging and other matters

It is important to consider construction staging early in the design process.

The earthworks balance and its distribution will determine whether sections can be completed independently and hence influence where temporary connections can be made. Haul roads and temporary stockpiles require space and this may influence the alignments. The construction of bridges, major culverts and the relocation of utilities are typically critical path activities and require consideration at an early stage.

Temporary works such as environmental controls (sedimentation control, noise barriers) require space and these may also influence cross-section and alignment.

For a more comprehensive discussion of constructability/maintainability see Appendix A.2.8.

Designer's responsibilities

A designer shall progressively check their own work during development of the design, recording clearly and concisely any design data used, calculations, analyses, considerations and assumptions adopted. The design outputs should be in accordance with the project requirements and presentation standards.

A designer, on reaching a checking hold point or completion of the design task, shall:

- compile all design data, design outputs and other relevant details
- sign and date the design documentation
- advise the project manager/leader that a checking hold point has been reached, or that the design task has been completed.

Where a design discrepancy has been identified either through self checking or by another checker, the designer shall review the implications of an amendment on associated design components.

A.2.3 Matters Specific to Each Design Phase

Phase 1 – Establish the Preferred Solution

For a more comprehensive description of this design phase see Section 4.2.1.

In establishing a preferred solution, it is expected that the designer will identify and consider (all) plausible solutions. This is generally taken to require a sufficiently broad enough range of options to allow for sensitivity to be assessed. The options used for formal comparison must be valid, i.e. they must comply with design standards.

The design is developed for each solution option to the extent necessary to allow the comparison of options. The earthworks are ‘balanced’ using notional designs for pavements and cross drainage, overall examination for issues such as aquaplaning, and construction sequence. Preliminary right-of-way impacts/requirements are identified. Account is broadly taken of future requirements including matters such as adding future lanes or upgrading interchanges. Consultations, with identified stakeholders, appropriate to the level of detail required should be undertaken.

Rather than an individual design report, the output from this phase is typically an options comparison report, recommending a preferred solution.

Phase 2 – Further Develop the Solution

For a more comprehensive description of this design phase see Section 4.2.2.

Further development of the preferred solution to give sufficient confidence that it can be built and meet requirements necessitates an increase in the detail.

Unlike options, this phase may have prior work done on the project and so the first stage is to consider that design documentation, especially important where a new team is engaged to deliver the preliminary design.

Where the project forms part of future works, it must be designed as part of the ultimate design.

In this phase, the output is often used for planning and environmental approvals for the project.

Phase 3 – Detail Design: the Design for Construction

For a more comprehensive description of this design phase see Section 4.2.3.

In this phase it is essential that a design is produced that is suitable for tendering and construction purposes.

Temporary works

Temporary works should be fully designed and should allow their construction to be completed.

As a guide, some specific issues that might be considered in this context include:

- Can the temporary work be constructed and removed?
- Can the appropriate geometry for the deviation be provided? e.g. lane shifts to create a work zone adjacent to a carriageway carrying traffic
- Is there room for temporary works such as retaining walls?
- Is material available at an early stage for detours and temporary fills?
- Can drainage function properly during staging?

A.2.4 Design Control

Responsibilities

The objective of the design control process is to ensure that during design development:

- The design is developed in a structured way so that project inputs are all addressed and integrated.
- Self checking of the design is carried out at appropriate stages.
- The planned arrangements for review, verification and validation are undertaken and are themselves structured.

Design development process

The flowchart shown in Figure A 3 illustrates the design development process.

The designer should be aware that the design of any unusual features should be carried out either by, or under the supervision of, a designer experienced in that area of expertise. In this context 'unusual' means something outside the design experience of the designer concerned.

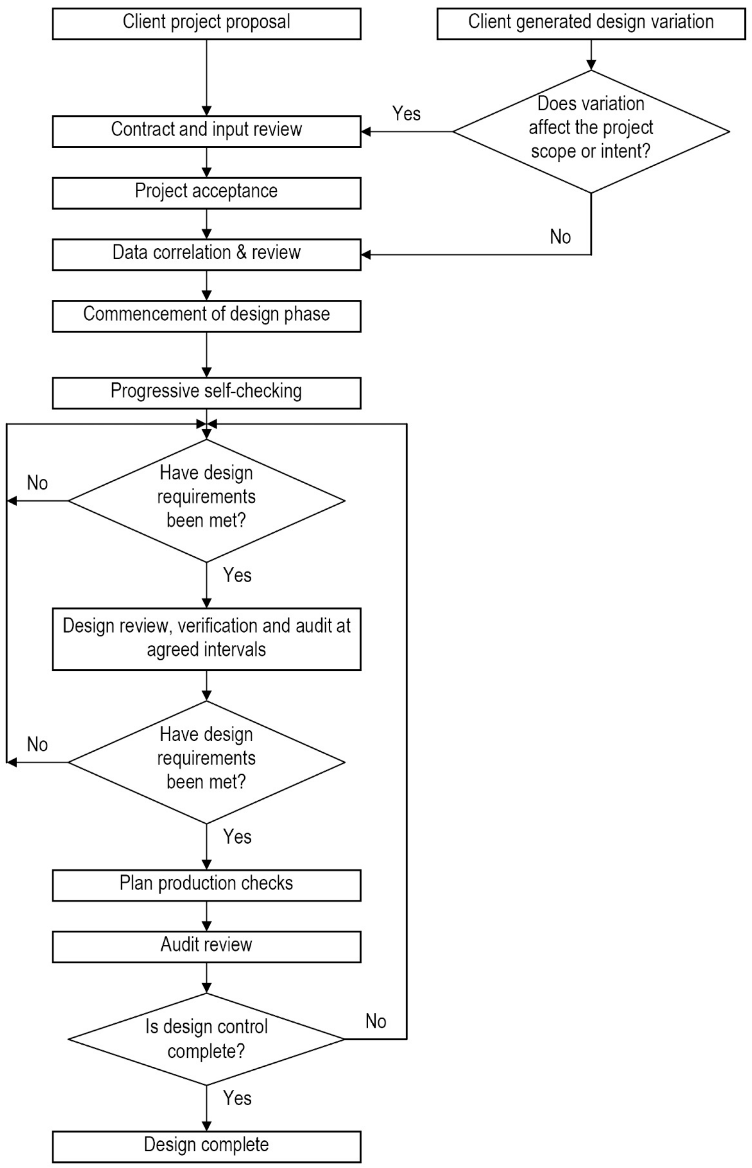
Detailing the design

In all phases of design, the design must finally be integrated. If ensuring that the many issues are satisfactorily resolved is the responsibility of the project manager, then bringing them together is the responsibility of the road designer.

Road agencies generally have standard drawings to cater for repeated issues. The designer should not overlook their inclusion as well as a check on their relevance/appropriateness.

Finally, detailing the design must confirm compliance with the input requirements including applicable statutory and regulatory requirements.

Figure A 3: Design and development process



Output presentation

Outputs should be delivered in accordance with the client's requirements (see also Appendix A.5).

A.2.5 Design Self Checks

The self checking of any design should be continuous and progressive to ensure that the application of design standards, principles, road safety and accuracy is built into the engineering solutions to achieve the project requirements and to avoid costly rework.

Self checking is not considered to be review.

However, the elements and issues are similar (Appendix A.3.3), in particular the aspect of the design where the designer asks the question, 'Can it be done better?' To some, this is the essence of good design.

Self checking can be done by the individual or the team as either a formal or informal process.

The purpose of the design output checks is to implement an appropriate number and level of progressive checks during the design stages to provide assurance that the design complies with the project requirements and objectives, design standards and principles, road safety criteria, and statutory and regulatory requirements.

Where the design is divided into several stages, design output checks apply to the outputs of each stage.

Progressive self checking should be done to ensure that each design step is based on the correct inputs, is properly laid out, accurately calculated and documented so that another person can understand and check what has been done.

A.2.6 Design Interfaces

Overview

ISO 9001 Cl 7.3.1 makes special mention of interfaces:

> *…manage the interfaces between different groups involved in design to ensure effective communication and clear assignment of responsibility.*

However, because a road project is required to link to other parts of an existing network there is an additional interface introduced into the design.

Therefore, design interfaces occur between:

- individually designed components within the project
- designed components and existing infrastructure/services/features.

Road design has the major accountability in this regard because it is the road designer who brings the overall design together.

Interface management

Road design has components that are developed by separate design disciplines.

Examples of areas that will be designed by groups other than road designers are:

- bridges
- other structures, including noise walls

- tunnels
- rock and earth structures, including retaining walls
- pavements
- landscape and urban design
- adaptive and electrical aspects of traffic signal design
- illumination and electrical aspects of street lighting design
- utility services.

For large projects, road design can also be split into packages which for efficiency in timing are often designed by separate groups within the same discipline.

An example of packaging for the road design discipline within a major project includes:

- geometry
- property adjustment
- clearing and fencing
- cross drainage
- longitudinal drainage
- pavement representation
- roadside furniture
- street lighting
- signs and markings
- utilities
- traffic control
- temporary works.

Each of these can be further separated on chainage.

The above illustrates the complexity of design packaging and hence interface control.

There are two aspects to interface management:

- continuity across the interface
- lack of interference.

Continuity

Continuity must be achieved for all components at all interfaces with the existing built and natural environment.

Continuity generally requires matching at the interface of:

- line
- level
- slope
- function.

This applies unless junctions or other devices are provided to allow for a change in these attributes.

As examples, junctions in the form of pits may be possible for constructed drainage, and junctions in the form of interface drainage may be possible for new pavement where it abuts existing pavement. Note that linear attributes of the road surface such as the centreline must be smooth and continuous.

In addition, where a project electronic model approach to design is used, the individual electronic design components must be checked to ensure that they fit precisely together.

Lack of interference

This is best illustrated with examples:

- A safety barrier such as a guardrail is generally represented as a linear feature in the plan and will typically be outside of any pavement or kerbing. However, in reality it has three dimensions and the posts, depending on jurisdictional requirements, will be driven to a depth of 1100 mm. There is a real danger that these will interfere with underground public utilities and road agency longitudinal drainage lines.
- At large signalised intersections, a cantilevered traffic signal may be required. Typically, they are represented as a short, linear feature on a plan. However, in reality they have three dimensions and the footings, depending on jurisdictional requirements, will be individually designed and may be of 1500 mm square in plan and 2000 mm deep. There is a real danger that they will interfere with underground public utilities and road agency drainage lines.

Procedure

The design management plan must address for interface control:

- how the road design is separated into components
- how the road design is separated into work packages
- how the various interfaces between designed components and packages are to be treated
- how the various interfaces between the designed components/packages and the existing infrastructure are to be treated.

It is essential that an experienced designer undertakes this activity.

It should be noted that some existing design software will specifically test for clashes.

A.2.7 Workplace Health and Safety/Safe Design

(see Section 4.8.2).

A.2.8 Constructability and Maintainability

(see Section 4.8.3).

A.2.9 Quantities

Road designers are generally expected to determine quantities.

A schedule of quantities is prepared as an output at the end of each design phase, primarily to allow estimating to be undertaken by others, but also, at an appropriate phase, to allow for comparison of tenders and to form an input for determining construction claims.

They are also used to assist the design process and examples include:

- earthworks where the calculated quantity is used to determine whether the alignments are giving balanced earthworks or not depending on requirements
- allow options for staging and construction methods to be explored for differences in cost.

Whilst quantities are generally considered to be a direct output from the design process, their calculation is not necessarily straightforward.

Some quantities can be determined from the electronic model, including earthworks and pavements. Others are still calculated by hand, although the model can deliver length measurements to assist (for example, the length of a specific section of kerb and channel). In many cases quantities are still determined manually, and therefore enough information should be given on the drawings to enable required quantities to be calculated.

Aspects of determining quantities that should be considered include:

- What degree of accuracy is required and what is available?
- What units are required and how are they determined if not in volume measures (asphalt is an example typically being ordered and priced in tonnes)?
- What is the effect of the drawing scale if manually extracting volumes?
- What assumptions have been made and what effect do they have on accuracy, for example
  - conversion from bank volume to loose or compacted volume
  - from where have pavement areas been measured (for example, lip line to lip line)
  - what allowance has been made in the earthworks quantity for stripped topsoil
  - what allowance has been made within the earthworks quantity for excavated material from utilities
  - what pavement thickness has been assumed and has it been deducted from earthworks? Has the pavement thickness changed?

The last dot point illustrates the issue of design changes. It is critical that after a design change all dependent matters are re-addressed, including quantities. Good document control is required.

The calculation of quantities should be treated as a step in the design process and should therefore be subject to self checking and review.

When self checking or reviewing, a ‘sanity’ check is useful. These are familiar to an engineer and might be described as an ‘order of magnitude’ check.

As with other design processes a checklist is a useful tool.

A.3 Design Review, Verification and Validation

A.3.1 Overview

The terms ‘review’, ‘verification’ and ‘validation’ are discussed in some detail in subsequent clauses. However, it is worth bearing in mind a simple differentiation for them.

It is noted that:

- verification may be described as ‘designing the product right’
- validation may be described as ‘you designed the right product’.

To continue this simplification, review may then be put in terms of ‘checking to see that verification will be successful but that in addition you have designed the best product’.

A.3.2 Independence in the Process

Independence in the process is covered in AS/NZS ISO/IEC 17020:2000 General Criteria for the Operation of Various Types of Bodies Performing Inspection.

It states that:

> *Inspection bodies carry out assessments on behalf of clients, with the objective of providing information to those parties relative to conformity with regulations, standards, or specifications. Inspection parameters may include matters of quantity, quality, safety, fitness for use, and continued compliance. Inspection of a product, may concern all stages during the lifetime of these items, including the design stage.*

It goes on to note that qualifications and experience are necessary:

> *Such work normally requires the exercise of professional judgement in providing the service, in particular when assessing conformity.*

It also notes that:

> *The requirement for the independence of inspection bodies varies according to legislation and market needs.*

In Clause 4.2 it states:

> *The inspection body shall be independent to the extent that is required with regard to the conditions under which it performs its services.*

It details three levels of independence – Type A, B and C.

Type A is the strongest, requiring a separate legal entity to do the review/verification/validation and is often used by road agencies in large contracts, carrying the title of an 'Independent Verifier' or similar.

Type B can be a separate and identifiable part of the same organisation and is often used by consultants and road agencies for review/verification/validation of major risk components of the design, for example, bridge design being reviewed by an office of the same company in another city/state.

Type C is the weakest of the requirements and the standard refers to it as 'The inspection body shall provide safeguards within the organisation to ensure adequate segregation of responsibilities and accountabilities in the provision of services.'

The choice of independence level is sometimes left to the design organisation, and it is expected that the level adopted will reflect the risk associated with that stage of the design. Sometimes the road agency may specify the level, and this may vary according to jurisdiction, project size and complexity.

As general guidance, the following considerations are applicable:

- Is the use of the same team appropriate or should another team/office do the review/verification/validation?
- Is the use of an alternative method appropriate or otherwise parallel calculations?
- If parallel calculations are chosen should they be separated in time or space?
- If the design stage is critical should parallel design be used?

A.3.3 Design Review

Overview and purpose

Design reviews are key elements of the quality system implemented at planned hold points on the design program.

ISO 9001 Cl 7.3.4 sets out two functions for the design review process:

- to evaluate the ability of the results of design development to meet requirements
- to identify any problems and propose necessary actions.

The first point to note is that it is an evaluation; a critical examination. Secondly, it is an assessment of ability, which combined with other statements, requires an element of prediction. Thirdly, it does not refer to the quality of the design process but rather refers to the results of the process. In road design, the results are more than just the physical road infrastructure but also include the often un-stated but necessary ability to be able to build it.

It goes on to require that:

> *….participants in such reviews shall include representatives of functions concerned with the design stage being reviewed and this again supports the review being undertaken during the design development process.*

The second bullet point above, ‘to identify any problems and propose necessary actions’ implies that the review is targeted toward identifying problems during the design development and not after, so that they can be corrected in a timely fashion.

Note that the fundamental requirements detailed above are concerned with the design's ability to meet, not exceed, requirements. In road design, the review process also has a wider function, reflected in some definitions of the term. This wider role is concerned with assessing whether the design will be the best possible within the constraints, and to achieve this, it is necessary to have a skilled and independent designer as part of the review team to challenge the choices made during the design development process.

Review should include consideration of all aspects of the design to assist with the evaluation and with completing quality assurance requirements including:

- availability of design documentation including drawings (project electronic model), design report and specifications
- the quality of the design itself
- structural and other engineering aspects
- constructability
- safety in design
- design integration
- design interfaces
- any unusual features of the design
- road safety audits performed and recorded at all stages
- engineering design certification (where required by the road agency).

It should be noted that review within the team sometimes called ‘checking’ or ‘self checking’ is considered to be part of the design development process (A.2.5).

Review should be carried out throughout the design development on one or more aspects of a design available at that stage of completion (Appendix A.2.2).

Timing and depth of design review

The number and timing of design reviews may vary depending on the type and complexity of the project, taking the client's requirements into consideration.

The authority for determining the frequency and the depth of each review required for a project will vary with the project but should be based on an assessment of:

- the type of project
- project complexity
- project risk
- knowledge and skills of the designer(s) involved
- technology being utilised

and taking into account the client's requirements.

Review activities must be adequately resourced and sufficient time should be allocated.

Design reviews should be undertaken at the end of each phase of the design (Section 4.2) and at key points within each phase including:

- development of traffic engineering layouts and the establishment of horizontal and vertical alignment
- prior to approval to the drainage strategy
- prior to fixing boundaries
- during the overview of the final design prior to signing of the drawings.

The review must be undertaken sufficiently early in each design phase to enable any recommended changes to be incorporated at minimum cost.

Where the client has provided a conceptual or functional design that has not been subject to a road safety audit, one shall be undertaken as part of the data correlation and review process to ensure the road safety aspects of the design have been addressed.

Design reviewer's capabilities

The number of members needed for a design review team will vary depending on the size and complexity of the project. The team must, for each discipline being considered, have knowledge of design standards and principles, construction and user safety, environmental issues, road construction techniques and requirements, and post-construction maintenance. If a road safety audit is not carried out separately, the design review team shall include at least one person who is competent in such audits.

For small projects it may be practical or necessary to have one person conduct the design review. In these circumstances the design reviewer shall be independent (Appendix A.3.2).

As noted in Appendix A.3.2, a reviewer (either a single person or a team) should be selected on the basis of experience and expertise required to competently evaluate the adequacy of the design.

Review responsibilities

Where a review activity identifies a conflict between the client's requirements and good design standards, principles, road safety, constructability and/or cost, the project manager should resolve the conflict with the client.

The reviewer shall identify whether:

- the design has been completed in accordance with the project requirements and objectives
- there have been omissions
- work shown on each drawing is technically adequate, meets the established standards and codes, and reflects the designer's intent
- the design is practical, economical and can be constructed
- there is, in the reviewer's opinion, a better design available.

Where a design discrepancy has been identified, the reviewer shall record and discuss the discrepancy with the designer.

The road safety auditor shall identify potential safety problems for the road users and others affected by the project.

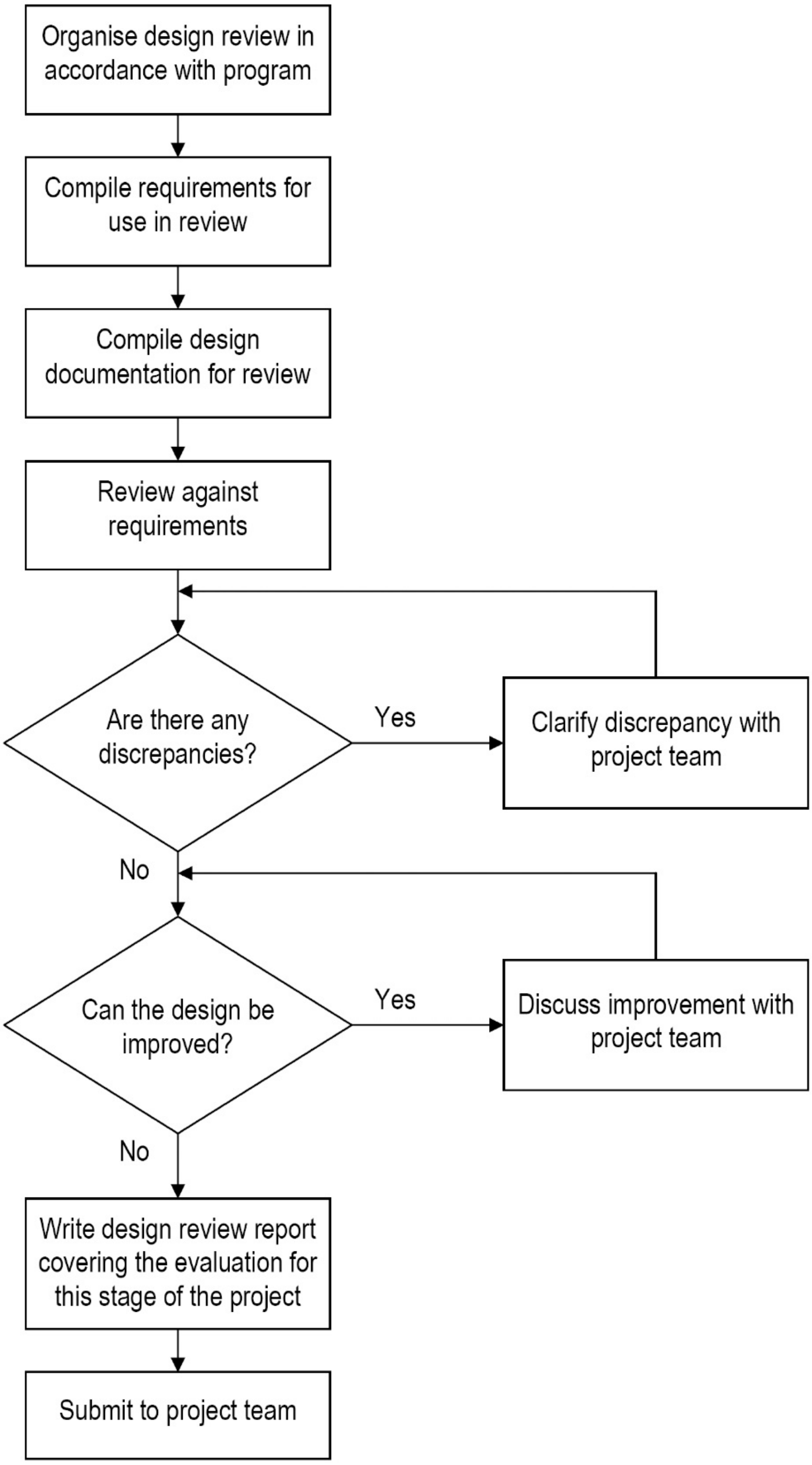
Design review process

The important aspects of this process that must be addressed include:

- Planned hold points for design reviews shall be included on the program.
- Road safety audit components of the design review shall be carried out as required.
- Issues raised in previous design review reports have been addressed by the design team and the outcomes recorded.
- All design checks shall be recorded to establish traceability and to demonstrate the depth of checking that has occurred. All design checking documentation shall be signed off and dated.
- A clear and concise design review report should be prepared, covering (a) road safety findings and recommendations if not reported separately, and (b) assessment of the total design for function, safety, constructability, maintainability, durability, project-specific requirements, statutory and regulatory requirements, aesthetics and economy.
- Design discrepancies are adequately reviewed and resolved taking into consideration the effect of design changes on already completed work and adjacent sections of design.

Figure A 4 illustrates the design review process.

Figure A 4: Design review process



Source: Adapted from VicRoads (1995).

Further considerations

The review has a technical basis and covers the layout, stage construction and implications for future development, and also a review of design input data adequacy. Further items to be considered in the technical review include:

- the design issues which have been considered (roadside features, rest areas and service centres, traffic volumes and composition, traffic lane width, public transport lanes, emergency lanes, land acquisition, cross-section elements, right-of-way constraints, vertical clearances)
- operating speed along the project with respect to topography, adjacent development, road function, cross-section, road classification, and road user expectations
- adequacy of alignment approaches to structures with respect to horizontal and vertical curves, superelevation development, and sight distance
- whether horizontal and vertical alignment provides satisfactory sight distance, along the road, at access points, and at pedestrian and cyclist crossings
- whether frequency of crossings is appropriate for safe access, disruption to traffic movement, access of emergency vehicles and public transport
- safety of proposed connections to existing road(s)
- provision for all road users
- consistency of design standards with respect to adjacent road standards
- potential for future upgrading
- stage construction considerations
- regulatory and statutory requirements affecting design
- identification of critical design controls
- adequacy of design input data.

Documentation

Records of the results of the review and any necessary actions shall be maintained.

This may take the form of a completed review checklist that will also provide a summary of the depth of the review. Supportive evidence of the satisfactory completeness of the review needs to be maintained and would generally include:

- minutes of meetings and discussions
- record of design brief review
- record of design review
- road safety audit report if reported separately
- correspondence seeking clarification or requests for information
- written response to the issues raised in the above requests.

A.3.4 Additional Aspects to the Review Process

Road safety audit

A road safety audit provides an additional safety component in the review.

Aspects of the road safety audit process are described in Section 2.2.3. Depending on client requirements, the audit may be undertaken separately from other parts of the design review, as part of the design review, or as an input to the design review.

Engineering review

Some elements of a road design require professional engineering input and must be reviewed by a competent engineer.

Examples of these elements are:

- bridge design
- geotechnical design
- structural design.

Review of these elements can be undertaken as part of the design review process provided the design review team includes at least one member with appropriate expertise. Separate reviews may be required in some cases or as input to a design review.

Constructability/Maintainability review

The intent of this part of the review is to check that a design can actually be built and as an extension to this, maintained. Note that it goes beyond the physical ability to build or maintain the work and includes the need to be able to do so safely.

Review of constructability and maintainability can be undertaken as part of the design review process, provided the design review team includes at least one member with appropriate expertise. Separate reviews may be required in some cases or as input to a design review.

Examples of items which may be considered for a review of constructability include:

- traffic operations during construction
  - appropriate geometry (alignment, transitions, tie-ins, cross-section elements)
    Careful consideration should be given to the standards to be adopted and care should be taken where reduced standards for short-term detours are adopted.
  - capacity
  - signing
- temporary works should be an integral part of the design
- temporary drainage must work
- drainage channels must be appropriate to the soil type
- drainage of sags, particularly in ramps, must be effective
- drainage at the ends of bridges must be properly directed to outlets
- surface drainage from high fills should be controlled with dykes and batter chutes or other positive control
- rate of rotation of crossfall must suit the capability of the paver – must document the start and end of all transitions
- widths of elements must be practical for the equipment available e.g.
  - widening appropriate to machine widths
  - width of paving suitable for the paver
- consistency of pavement layers on adjacent sections in particular pavement depths on adjacent sections should be rationalised for small differences in depth
- pavement layers should be continued under relieving slabs and small traffic islands

- appropriate materials for use under traffic are required to ensure safety and integrity of the works during construction (e.g. intermediate sealing of surfaces to be used by traffic even if they are to be covered later)
- on concrete pavements
  - clear detailing of joint types, dimensioning and block-outs for drainage structures
  - clear description of the type of joints to be used and their extent
  - ensuring that traffic detector loops are not located under reinforcement
  - ensuring that the cutting of traffic detector loops into concrete is taken into account in the pavement life calculations, that is, a deeper pavement should be provided or pavement life will be shortened
- complexity of construction at individual locations (e.g. at bridge abutments – drainage details, safety barrier, poles etc.)
- conflict between different items of road furniture (e.g. location of light poles behind safety barrier)
- conflict between road furniture and drainage pits.

Similar considerations should be applied for maintenance activities, particularly adequate space and access for plant required for maintenance such as for shoulder grading and median mowing.

Review of OHS in design/safe design

A process for incorporating occupational health and safety (OHS) concerns is outlined in A.2.7.

It was noted there that decisions taken in the design process influence the way in which a project will be built, maintained, operated and ultimately decommissioned. The risks posed to workers vary with the different approaches taken and there is an onus on designers to minimise those risks wherever possible.

Fundamentally, reviewers must identify whether, in the first instance, the design can be safely constructed/maintained and then whether the design can be changed so that any remaining risks to workers are removed or reduced.

Most likely, the review will be carried out by a team so that the required skills can be assembled. These skills include:

- construction and maintenance techniques
- OHS skills including knowledge of relevant legislation
- additional design skills
- member(s) of the design team.

The recommendations arising from the review should be documented.

A.3.5 Design Interface Review

The issues around the integration of design components and ensuring that interfaces work are discussed in Appendix A.2.6.

It is an area where problems often arise and it is essential that appropriate resources are applied to the design development and the review of interfaces both within the design and to its junctions with the existing built environment.

A.3.6 Incorporating the Review Response

The process for dealing with issues arising within the documented design review report will depend on the contractual arrangements, the phase of design being considered, the depth of the review and the degree of independence utilised for it.

For straightforward design issues, the design team will, most likely, be the appropriate arbiter to decide whether to incorporate the change. However, for matters involving a significant change to the design including a change in scope, then generally the client or project manager should determine the issue.

The outcome of the determination should be documented and typically this would occur within the design report.

A.3.7 Dealing with Design Non-conformance/Departures

Control of non-conforming product in design

It is possible to distinguish between a non-conformity and a defect. A non-conformity being the non-fulfilment of specified requirements (identified in processes such as review or verification), whereas a defect may be described as the non-fulfilment of intended usage requirements (identified in a process such as validation or in-service complaints). A non-conformity may not cause a product to be un-serviceable and a defect may still exist with a conforming product.

Thus a design non-conformity occurs where the design output does not meet (client) specified requirements and may be either an omission, an error or for various reasons, an inability to meet the requirement. It may be detected during the self check, review, verification or audit process.

The nature of the non-conformity will determine the process used to remedy it.

The nature of the non-conformity will depend on the rigidity of the 'input rule' that it does not meet and whether it can be 'fixed'. The input rule may be classified as either:

- a client-developed requirement (for example, design criteria in a project brief)
- a referenced standard (for example, the *Guide to Road Design*).

Clause 8.3 of ISO 9001 requires that a non-conforming product shall be dealt with by one or more of four ways of which the following two are relevant to road design:

- by taking action to eliminate it
- by obtaining a concession for it from the client or relevant authority.

Thus for road design, it may result in either reworking or a design departure/exception. Unless a design departure/exception is agreed then reworking is required. Design departures/exceptions are further discussed in Section 4.5.1.

It should be noted that if the use of EDD is allowed by the road agency for the particular issue then its use will not be considered to be a non-conformity.

A.3.8 Dealing with Variations

Design variation

Design variations are defined as modifications to the original design requirements that have been initiated independently by the client or through designer recommendations. Variations are not changes that have occurred due to design errors or omissions by a designer or design team.

Where variations have been initiated by the client, the designer should review the proposal in accordance with the procedures outlined in Appendix A.1.

Where variations are proposed by the designer, it is expected that sufficient justification should be provided to allow the client to fully evaluate the proposal.

A design variation should be reviewed against the original project scope and intent prior to implementation to ascertain the implications of the change on the overall project, and should include an assessment of the effect on design.

All variations in design should be subjected to the same design verification process as the initial design.

A.3.9 Design Development Verification

Overview and purpose

Design development verification is a key element of the quality system implemented at planned hold points on the design program.

ISO 9001 Cl 7.3.4 sets out one function for the design verification process:

> *….to ensure that the design development outputs have met the input requirements.*

Verification may be described as a review with the aim of certification. Therefore, it has the characteristics generally required of review together with the act of certification.

In summary, verification may be simply described as ‘designing the product right’ .

There are some differences between verification and review, in that verification:

- does not require that participants shall include representatives of the design team
- is not usually held during the design development but rather at the end of it
- is not targeted toward identifying problems during the design development so that they might have been corrected in a timely fashion
- does not have the function of identifying whether the design could be better, simply whether it conforms.

Verification must include consideration of all aspects of the design to assist with the evaluation and with the certification including:

- availability of design documentation including drawings (project electronic model), design report and specifications
- the quality of the design itself
- structural and other engineering aspects
- constructability
- safety in design
- design integration
- design interfaces
- any unusual features of the design
- road safety audits performed and recorded at all stages
- engineering design certification (where required by the road agency).

The fundamental purpose of the design verification is to assess the compliance of the project components with the client requirements. These include design standards, principles, constructability, maintenance and cost and the broader issues of road network strategies, aesthetics, environment and community concerns and their integration.

The objectives of the design verification are to ensure that the design:

- meets client requirements
- complies with statutory and regulatory requirements
- is practical, cost-efficient and provides a sound approach to road safety
- criteria, assumptions and consideration are correct
- documentation is accurate and functional.

Design verifiers

The number of members needed for a design verification team will vary depending on the size and complexity of the project. The team must have, for each discipline being considered, knowledge of relevant design standards and principles, construction and user safety, environmental issues, road construction techniques and requirements, and post-construction maintenance.

For small projects it may be practical or necessary to have one person conduct the design verification. In these circumstances the design reviewer shall be independent (see Appendix A.3.2).

As noted in Appendix A.3.2, a verifier (either a single person or a team) should be selected on the basis of experience and expertise required to competently certify the adequacy of the design.

Design verifying requirements

The verification practices employed should be appropriate to the cost of the work, the complexity of the design, and the client's requirements.

Verification of the design shall not be limited to checking of the original arithmetic calculations. Design verification shall ensure that:

- the correct inputs have been used
- there have been no omissions
- the design outputs can be traced to the design inputs including any variations agreed by the client
- any variations have been subject to the same checking processes as the original design.

Verification may include:

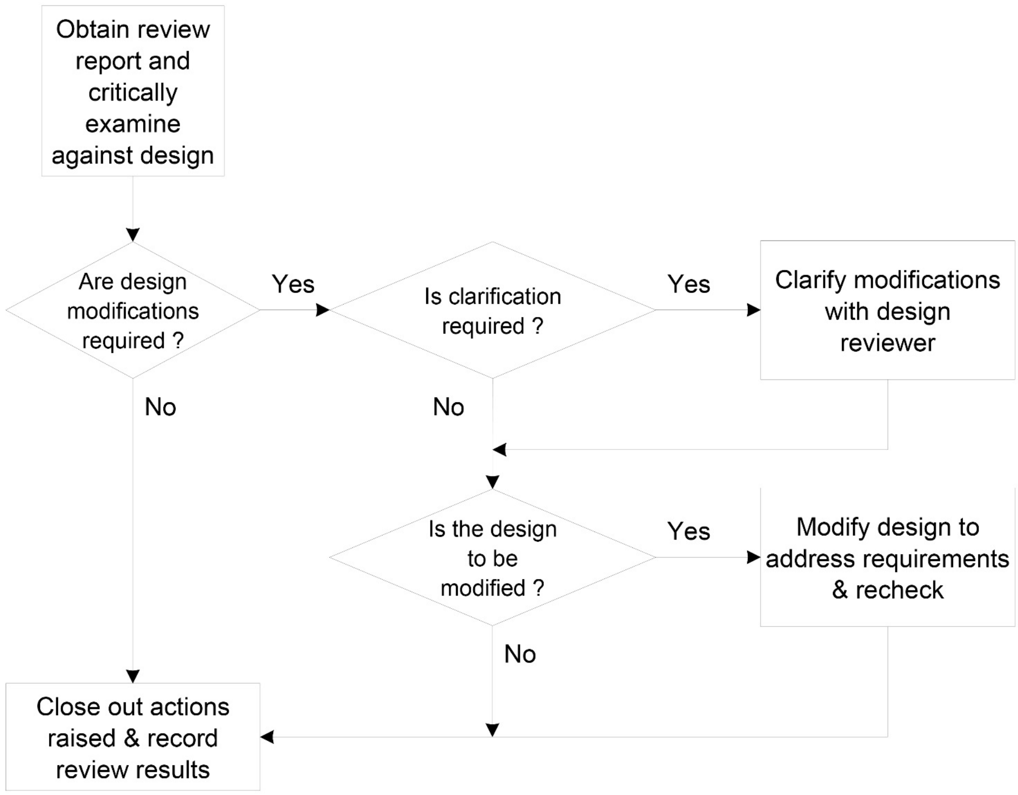
- performing alternative calculations
- checking a sample of the design calculations
- comparing the new design with a similar proven design
- undertaking tests and demonstrations of new appurtenances
- reviewing the design stage documents before release.

Figure A 5 illustrates the design output checking process.

The important aspects of this process that should be addressed are:

- The outputs of design meet the client's requirements expressed as inputs to the process.
- Design discrepancies shall be reviewed adequately and resolved, taking into consideration the effect of design changes on already completed work and adjacent sections of design.
- All design checks shall be recorded to establish the traceability and to demonstrate the depth of checking that has occurred. All design checking documentation must be signed off and dated.

Figure A 5: Incorporating results of review process



Source: VicRoads.

Checking aids

The following checking aids provide guidance in the design output checking process for the major elements of road design:

- horizontal and vertical geometry
- intersection layouts
- drainage.

Horizontal and vertical geometry

- Horizontal control criteria including: minimum lateral clearance to non-relocatable structures and services; minimum clearance to right-of-way; operating speed, horizontal curve criteria, superelevation requirements; overtaking provisions; cross-section requirements, location and type of intersections and/or grade separated interchanges; median, outer separator and emergency access locations; public transport requirements; stage construction requirements; and pedestrian and bicycle requirements.
- Vertical control constraints including: structure clearance controls; clearances to services; control levels; drainage controls; crossfalls; and re-sheet/overlay controls.

- Coordination of horizontal and vertical geometry including: conformance with terrain; grade changes; adequate lengths of straight; horizontal and vertical geometry in phase; sufficient passing opportunities; alignment approaches to structures; operating speeds; horizontal and vertical sight distance; sight distance for side road approaches, superelevation rotation; design level controls; and clearances to horizontal and vertical boundaries.

Intersection layouts

Design criteria, including:

- traffic details – volumes; composition; turning volumes; and pedestrian and bicycle requirements
- design vehicles
- public transport requirements
- property access requirements
- horizontal clearances
- operating speeds on approach legs
- intersection cross-section
- turn lane treatments
- median treatment
- vertical grades and grading controls.

Design checks, including:

- satisfactory alignment for approach, through, and departure
- intersection sight distance on all approaches
- truck stopping distance
- truck clearance time
- visibility of islands, auxiliary lane treatment and diverge and merge areas
- clearances to above ground and underground services/utilities
- clearances to structures
- island details and layout
- auxiliary lane treatments
- turning for design vehicles (clearances).

Drainage

Drainage control checks including:

- drainage strategy
- legal considerations
- drainage authority requirements
- plans covering entire catchment and relevant surface features
- drainage reserves
- adjacent property use

- environmentally sensitive areas
- geological report
- location of outfalls and responsible authority
- area affected by flood and flood levels
- details of existing drainage system
- design criteria
- bridge design responsibilities.

General drainage checks including:

- grading of the road with respect to flood levels, groundwater levels, flow across superelevation development, flow velocity, outlet conditions, subsurface drainage, and landlocked sags
- drainage diversions such as catch drains, table drains and noise attenuation mounds
- strategic assessment of contributing catchment and available outfalls
- maintenance and construction requirements.

Network drainage checks including:

- appropriate pit types provided at all low points
- pit locations do not conflict with driveways etc.
- pavement surface flow widths in accordance with design criteria
- pipe network appropriate
- pipe calculation components
- data used and hydraulic gradeline calculations
- pipe flow calculations
- provision for major storms
- outfall protection treatment.

Culvert design checks.

Catch and table drain checks.

Sub-surface drainage checks.

Documentation

The completed checking aids list provides a summary of the depth of the design output checks. Supportive evidence of the satisfactory completeness and compliance of the design outputs needs to be maintained and would generally include:

- minutes of meetings and discussions
- record of design variations
- record of design discrepancies
- correspondence seeking clarification or requests for information
- program of works.

A.3.10 Design Development Validation

Overview and purpose

Design validation is a key element of the quality system implemented at a planned hold point(s) at the completion of a design program.

ISO 9001 Cl 7.3.4 sets out one function for the design validation process:

> *….to ensure that the resulting product is capable of meeting the requirement for the specified application or intended use.*

For road infrastructure this requires that validation is the process whereby it is determined whether the project meets the needs of the intended user of the infrastructure. Note that this may include those not directly using but affected by the infrastructure.

In summary, validation may be simply described as ‘you designed the right product’ (Appendix A.3.1).

Therefore, the fundamental purpose of the design validation is to assess the effectiveness of the project design (and implementation) and might include:

- road safety
- road network efficiency
- life expectations
- aesthetics
- environment and community concerns
- constructability
- maintainability
- cost.

The methods used will vary and depend on both the product and the aspect of it being considered. In road design it is difficult to test the product completely until it has been built. Thus validation is often deferred until completion. However, it is possible to partially complete validation by the use of modelling on a complete design and by appropriate consultation.

Methods available for validation would include:

- consultation during development and after the project has been completed
- modelling based on the design
- inspections of completed product including the road safety audit required after completion of the project
- surveys conducted on the finished product including network efficiency and accident history
- complaints register.

Design validators

The nature of the validation method(s) and the size and complexity of the work will determine the composition of the team. The road designer or design team will not usually manage the validation process. That task would reside with the project manager. However, the road designer may and perhaps should be involved in appropriate parts of the validation process (see Feedback to design below).

The team must have, for each discipline being considered, knowledge of relevant standards and principles and survey techniques and requirements.

For small projects it may be practical or necessary to have only one person conduct the design validation.

Unlike verification it is not usual to have a certification provided in total, rather the certification may be required for individual elements of the project for example post-construction noise measurement. The process generally delivers independence because of the specialist nature of the assessments. Needless to say, the design validator should be independent (Appendix A.3.2).

As noted in Appendix A.3.2, a validator (either a single person or a team) should be selected on the basis of experience and expertise required to competently certify the adequacy of the design.

Design validation requirements

The validation practices employed should be appropriate to the cost of the work, the complexity of the design, and the client’s requirements.

Feedback to design

It is important that issues identified in the validation process be captured, in particular those related to the design process for the project. Because of the nature of road infrastructure, it is not usually efficient or effective to make changes after a project has been constructed. However, if issues related to design are identified, then corrective action can and should be incorporated into the quality system for subsequent projects.

A.4 Design Audit Process

A.4.1 Overview

ISO 9001 requires at Clause 8.2.2 that the design organisation:

> *…shall conduct internal audits at planned intervals to determine whether the quality management system*
>
> *a) conforms to requirements, and*
>
> *b) is effectively implemented and maintained.*

It should be noted that internal audits are also called first party audits and that external audits are generally those termed second and third party audits (Notes 1 and 2 to Cl 3.1 AS/NZS 19011:2003).

Road agencies (or other clients) may conduct or require that second party audits be carried out either as a part of prequalification/registration or as part of a design contract for a specific project.

Road agencies (or other clients) may require that third party audits be carried out either as a part of prequalification/registration or as part of a design contract for a specific project.

Road agency design audits have been typically classed as ‘system' or ‘product’ audits. Whilst a system audit may use a specific project to access the designer's quality management system, it is aimed at the elements of the system that are in use, whereas a product audit is targeting conformance to specified requirements, in particular, the Guide to Road Design or other road agency reference document. It would be expected that a product audit would also trace non-conformances back to system deficiencies.

ISO 19011 was written for auditing quality (and environmental) management systems but does give the following advice for product auditing:

> *In addition, any other individual or organization with an interest in monitoring conformance to requirements, such as product specifications or laws and regulations, may find the guidance in this International Standard useful.*

The following sections provide guidance in applying the audit process (also refer to Figure A 6).

A.4.2 Design Process Audit

Purpose

The purpose of the design process audit is to ensure that the control process has been completed in accordance with the program and quality plan, and that all client requirements and issues have been addressed and closed out.

The objective is to establish that:

- the requirements of the designer's quality management system have been met
- the requirements of ISO 9001 have been met
- all requirements raised either by the client or project team that will affect the quality assurance of the project have been addressed and closed out
- all programmed checks and reviews of the design and plan production have been adequately completed
- discrepancies that have been identified are adequately addressed and closed out.

Design process audit procedure

Typically, an internal auditor would undertake the audit in consultation with the project team.

A critical part of the audit process is determining the scope of the audit. In design, the scope may be set in conjunction with the design phase (Section 4.2) being considered and the stage reached within that design phase.

Some important aspects of this procedure are:

- the traceability and completeness of all checking and review documentation including supervisor's checks
- the adequate review and resolution of design discrepancies, taking into consideration the effect of the changes/amendments on the total project
- the traceability of the design documentation such as variation orders, approval and agreement to design modifications and extension of time
- the traceability of design requirements in the design outputs
- closing out of all corrective action requests (CARs) raised against the project.

Where any part of the control process or requirements are incomplete or difficult to establish, a non-conformance needs to be issued. The design process review will not be completed until all non-conformances have been addressed and the short-term corrective action has been closed out.

The design process review shall be conducted as a quality compliance audit. To achieve an adequate rating for any item objective evidence must be provided.

A.4.3 Design Product Audit

Purpose

The purpose of the design product audit is to ensure that the design has been completed in accordance with the requirements of the design reference documents (including Parts 1 to 7 of the *Guide to Road Design* where this is the primary reference) and that all client requirements and issues have been addressed and closed out.

The objective is to establish that:

- the requirements of the client's design reference documents have been met and exceeded
- all requirements raised either by the client or project team that will affect the quality assurance of the project have been addressed and closed out
- discrepancies that have been identified are adequately addressed and closed out
- related system deficiencies have been identified.

Design product audit procedure

Typically, an audit team, including specialists in the design disciplines being audited would undertake the audit in consultation with the project team.

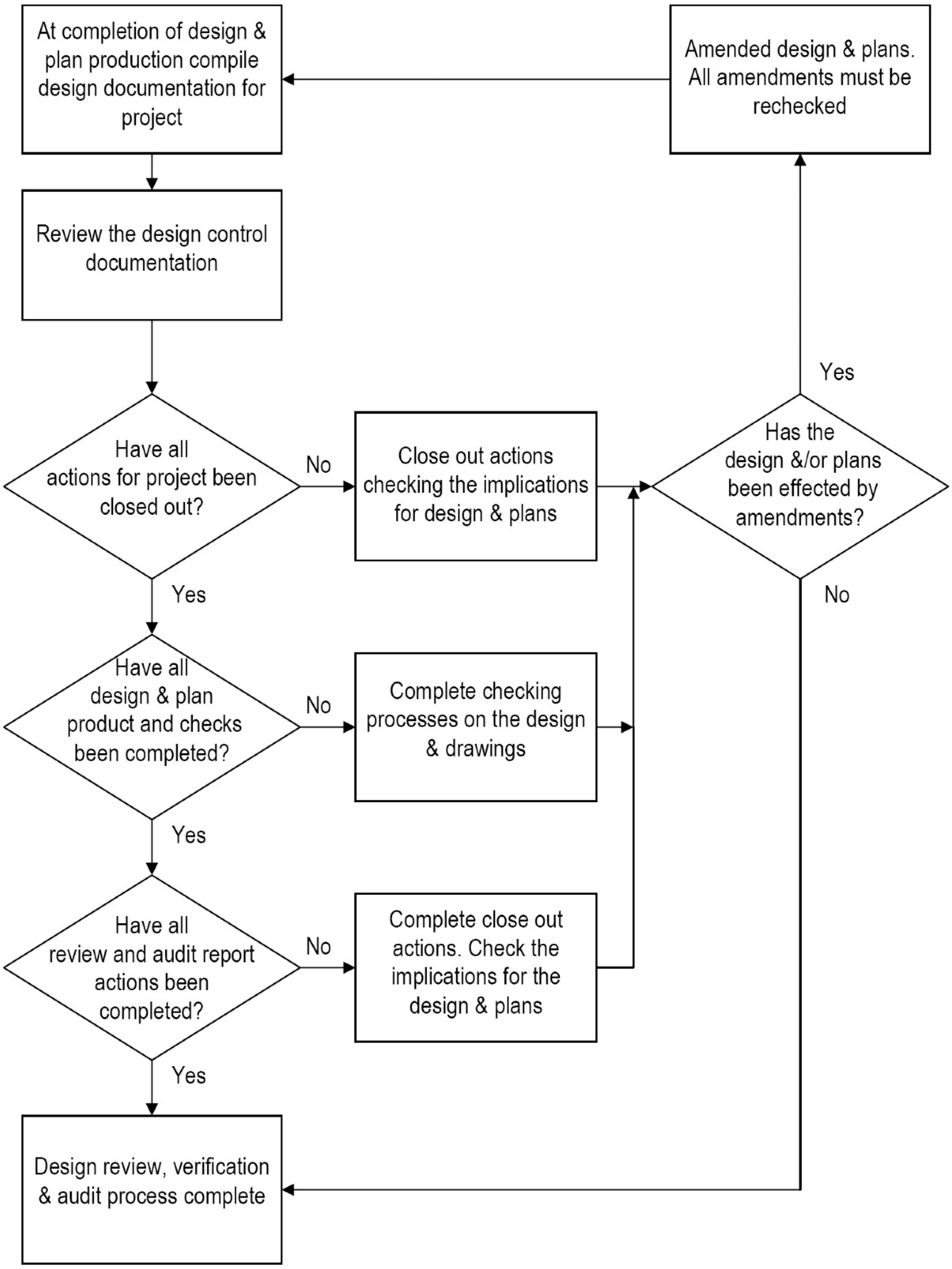
A critical part of the audit process is determining the scope of the audit. In design, the scope may be set in conjunction with the design phase (Section 4.2) being considered and the stage reached within that design phase.

Some important aspects of this procedure are:

- checking conformity of the design to requirements
- assessing whether the design is the ‘best’ design that can be produced
- review and resolution of design discrepancies, taking into consideration the effect of the changes/amendments on the total project
- the traceability of the design documentation such as variation orders, approval and agreement to design modification and extension of time
- the traceability of design requirements in the design outputs
- identifying non-conformances and the related system deficiencies
- closing out of all non-conformances and corrective action requests (CARs) raised against the project.

Where any part of the design has been found to be incorrect, a non-conformance shall be issued, the related system deficiency identified and a corrective action request issued on the system. The design product audit cannot be completed until all non-conformances have been addressed and the corrective actions have been closed.

Figure A 6: Incorporating design review, verification, and audit process



Source: Adapted from VicRoads (1995).

A.5 Presentation of Outputs

A.5.1 Overview

Computer aided design (CAD) can be represented by an electronic 3-D model and that model can also be used directly for construction or for the production of drawings using computer aided drafting software.

Alternatively, a design may be represented in a 2-D electronic format using computer aided drafting software.

Manual drawing is still used either to assist in the design process or where circumstances require its use, but generally not as a production method.

The advantage of a standard for preparation and presentation of design is to:

- distinguish between components of the design
- promote consistency especially with the advent of electronic models
- adequately convey the design intent
- provide enough data for construction and asset maintenance.

For specific presentation details, refer to the road agency's presentation requirements.

Following is a list of issues that a computer aided design and drafting (CADD) standard should include:

- typical sheet contents
- organisation of CADD data
- preparation of CADD drawings
- Phase 2 design composition
- Phase 3 design composition
- standard feature labels for data groups
- standard symbols
- supplementary design elements and criteria.

Each of these is expanded below.

A.5.2 Typical Sheet Contents

Typically sheets would contain:

- title
- revision history
- client
- designer.

A.5.3 Organisation of CADD Data

Issues that might be considered include:

- definitions
- data groupings (models)
- features (strings or objects).

A.5.4 Preparation of CADD Drawings

Issues that might be considered include:

- presentation
  - plan size and scale
  - plan borders

  - line thickness and fonts
  - symbols
  - design feature reference points
  - plan orientation
  - standard notes on drawings
  - title blocks
  - plan registration
  - hatching and shading standards
  - limits of work
  - reports
  - data transfer
  - file naming conventions for CADD files
- plan groups
  - drawing groups (for example, plan and long section, pavement marking)
- compilation
  - order of drawings (together with the issue of how to treat large projects where many volumes are involved).

A.5.5 Phase 2 – Design Composition

A Phase 2 design might include any of the elements from a Phase 3 design but typically would be composed of:

- alignment plans
- longitudinal section
- typical cross-sections
- detailed cross-sections
- drainage design, including pipe long sections and pit schedules
- design report
- design documentation
- 3-D visualisation.

A.5.6 Phase 3 – Design Composition

Depending on scope and complexity, a Phase 3 design might include:

- cover
- amendments
- index
- supplementary drawing schedule
- typical cross-sections
- survey control diagram

- alignment control
- plan and longitudinal sections
- setting out
- drainage
- stormwater management
- subsurface drainage
- drainage profiles
- design contours
- structure details
- public utilities
- pavement composition – build-up, new
- pavement marking, signposting and safety barriers
- profiles
- cross-sections
- earthworks
- traffic signal design
- stage construction
- property adjustments
- landscaping proposals
- detail design report
- detail design documentation

A.5.7 Standard Feature Labels for Data Groups

Labelling standards would usually be required for the following data groups:

- design feature labels
- survey feature labels
- long section feature annotations
- cross-section feature annotations
- drainage feature labels
- drainage utility feature labels
- design and ground contour feature labels
- design and ground triangulation feature labels
- merged design and ground feature labels
- concrete jointing feature labels.

A.5.8 Standard Symbols

Standard symbol standards would usually be required for the following feature groups:

- standard survey features
- standard design features.

A.5.9 Supplementary Design Elements and Criteria

Supplementary documentation typically in the form of standard drawings and specifications would be required for the following elements:

- drainage
- kerbs, channels and safety barriers
- cross-sections
- property adjustments
- landscaping
- geotechnical
- survey marks
- public utilities
- pavement designs.

Appendix B Geotechnical Investigations and Design

B.1 Introduction

B.1.1 Purpose of Geotechnical Investigations

The purpose of a geotechnical investigation is to provide the designer with answers to questions such as:

- What are the geotechnical characteristics of the ground that could influence the design solution such as the location of rock, ground water or unsuitable materials?
- How will the ground respond to changes created by the proposed road design?
- What is the suitability of locally available materials for road construction purposes?
- Where is the nearest source of suitable pavement material?

Sufficient geotechnical information should be available for the designer to appreciate the limitations (and opportunities) that site conditions and availability of road making materials may have on the final road design solution. The designer should have a basic understanding of the following fundamental geotechnical issues:

- An increased load on the ground associated with fill embankments and structural foundations increases stresses on the ground and may induce settlement or bearing failure.
- Reducing the load on the ground such as in cuttings or other excavations reduces side support possibly causing destabilisation of adjacent areas.
- Excavations intercept, or change the level of ground water which can alter the strength or stability of adjacent material.
- Intercepted ground water to be discharged into the surface drainage system may contain dissolved salts or sulphates that would have an adverse effect on the environment.

The task of a geotechnical engineer is to predict how the ground is likely to behave under the changes proposed in a road design and associated construction activities, and to recommend how risks associated with such changes can be mitigated.

The results of a geotechnical investigation may influence a number of aspects of a road project. A knowledge of ground conditions and material strengths along the route may influence road design decisions regarding the road profile, the cross-section, or even the alignment if, for example, an isolated area of unstable foundation material is revealed by the geotechnical investigations.

B.1.2 Scope of Guidance

This section enables designers to:

- appreciate the importance of geotechnical investigations and how road design outcomes and other design activities are influenced by site conditions, associated ground response, geological hazards and locally available materials
- prepare conceptual drawings so that the grade line, cross-sections and the location of various structures can be determined in sufficient detail to facilitate a detailed geotechnical investigation
- prepare a brief for a geotechnical investigation or alternatively, provide sufficient information for the geotechnical services supplier to produce an investigation proposal
- consider the risks and hazards associated with the site conditions and to develop a road design solution where risks are kept within acceptable limits having regard to the size of the project and the importance of the road

- understand the implications site conditions may have on road construction costs and the development of cost-effective road designs
- gain an understanding of geotechnical terminology, concepts, field investigations, laboratory tests and risks associated with various design solutions.

B.1.3 Aims of a Geotechnical Investigation and Design

General

Geotechnical investigation is a term that is applied to the performance assessment of in situ and imported materials that are intended to form part of the project roadworks. This could include an evaluation of the (based on Main Roads Western Australia 2016):

- extent of topsoil stripping undertaken to remove and/or stockpile any vegetable matter or seed bearing soil prior to the earthworks phase

  The depth of required stripping may not always be apparent and accordingly, it may be appropriate to seek geotechnical advice regarding the most suitable depth for a particular project.
- strength/residual life of existing pavements, to estimate the remaining design life of the pavement and inform any strengthening requirements
- subgrade for pavement design purposes to enable suitable pavements to be constructed, which may impact on the extent of the earthworks required to construct the design pavement
- embankment foundations typically assessed from test pit or borehole information along the route, depending on ground conditions
- proposed cuttings to assess the presence of rock and/or subsurface water

  A variety of equipment is used and may include dozers to carry out excavation trials in rock cuttings, or the taking of bore samples. An evaluation of any discontinuities may be important in determining the most effective cut slope angle for initial and long term stability. Seismic refraction (acoustic) surveys are sometimes used to assess the indicative rippability of in situ materials.
- the stability of embankments where the design profile is well above natural surface, and/or where steep batter slopes are required, and/or where the toe of fill may be subject to erosion due to the presence of a moving water body (i.e. toe scour)

  The settlement potential under high fills may also need to be considered including a requirement for pre-loading. Where soft or wet soils are encountered, additional boreholes and test pitting may be required.
- proposed pavement material

  In situ materials found along the alignment are tested to confirm the quality of locally available road building materials. A detailed evaluation of these materials should be undertaken to determine their best use. For pavement design it is also important to know the soaked and unsoaked CBR (California Bearing Ratio) of the material that will form the subgrade and the amount of traffic the road is required to carry over its design life.
- bridge foundations

  Investigations are normally carried out in accordance with AS(/NZS) 5100:2017 in Australia or in the New Zealand *Bridge Manual* (NZ Transport Agency 2016). The information assists with decisions relating to the type of foundation appropriate for the location. Load-bearing reinforced soil structures also require an evaluation of foundation bearing capacity. Large culverts, particularly those that will be located on wet or soft soils may also require a foundation investigation.

- presence of ground water and its chemical composition

  Water chemical composition, e.g. pH, can be important when corrugated steel pipes are being considered or where salt water is likely to be encountered. A resistivity analysis will assist in determining the risk of accelerated corrosion of the steel pipes. For concrete pipes in a saline environment, water quality testing will allow an analysis of the risk to the reinforcing steel. In some areas there is a possibility of encountering acid sulphate soils and in these situations appropriate management plans need to be developed and implemented, refer also to Appendix B.7.6.

  Consideration should also be given to the erosive power of stormwater discharging from culverts. The information can be used to assess the design velocity that best suits local soils and assist to minimise downstream erosion potential.

- earthquake induced liquefaction, slope instability and ground deformation

  This typically involves investigations utilising boreholes and cone penetration tests (CPTs) to assess the potential for earthquake induced liquefaction and associated effects on structures. This is typically part of the design process in New Zealand and is covered in more detail in the NZ Transport Agency *Bridge Manual* (NZ Transport Agency 2016).

While some of these aspects can be addressed by knowledge of past performance in similar geological and climatic conditions, these studies should be carefully considered for all road projects. Geotechnical investigations should be initiated as soon as possible in the design phase, particularly where substantial detail is required, so that project construction programs are not adversely affected.

Extent of geotechnical investigation

A comprehensive geotechnical investigation of the project site is generally carried out in order to reveal and quantify the site conditions, and to characterise road making materials that will be encountered during the construction and operation of the project. This includes the nature, variability and extent of potential materials, and any special requirements to be observed. The investigation will normally include an evaluation of the local geology and hydrogeology[5]. The detail of the investigation should be commensurate with the potential risks, hazards and complexity of the project. It would typically include:

- geological surface mapping
- sampling of soils with logging of test pits and boreholes
- ground water sampling
- logging of existing cut slopes and excavations
- field testing including field monitoring
- measurement of ground water levels
- moisture regimes
- laboratory testing including soil strength and compressibility of the soil
- analysis and interpretation of the field and laboratory test results
- preparation of a geotechnical factual report
- preparation of a geotechnical interpretive report.

5 Hydrogeology is the distribution and movement of ground water in soils and rocks.

It is not necessary for designers and project managers to understand all of the details associated with the provision of a geotechnical investigation, but it is important to have an appreciation of the range of tests that can be called upon to assist in developing the most suitable road design solution. It is also good practice to contact a professional in the geotechnical field who can advise of the need for particular types of investigation that may be required to adequately describe the site.

A key output of a geotechnical investigation is the provision of a three-dimensional conceptual representation of subsurface conditions along, and in close proximity to the proposed road alignment. This representation may take the form of a written description, maps and cross-sections to provide the designer with an understanding of the materials and environmental conditions that might be encountered and affected during the proposed road project. The representation should include identification of material properties, mass properties, and environmental properties as shown in Table B 1.

Table B 1: Typical output of geotechnical investigations

Output	Description
Material properties	Physical characteristics of the subsurface and road building materials. For example, what types of rock or soil are present and what is the spatial distribution.
Mass properties	Physical features within the ground that could influence ground response. Examples include joints in rock, faults, fissures in clay, buried valleys and bedding.
Environmental properties	Environmental effects on the subsurface conditions such as ground water level and flows, and the effects of weathering.

All of these properties help to explain how the ground is likely to respond and a geotechnical investigation should provide guidance on each of these matters. For example, highly jointed granite may respond very differently compared to intact granite, even if the rock classification is identical. If ground water is flowing through the joints, the response may be different again.

The degree of detail that is required will depend upon the variability of the subsurface conditions, the design stage (e.g. feasibility or detailed design), importance of the road and the level of geological uncertainty (risk) that can be accepted on the project. Further detail on what features are important for various aspects of road design are covered in Appendix B.4.

Where changes of soil type are encountered, the investigations should be sufficient to enable suitable adjustments to the design elements to be made and the need for any special treatments to be assessed.

During the conceptual design phase, a broad investigation is generally undertaken to assess land requirements to inform option selection. For a project where a detailed design is separately prepared, a comprehensive geological investigation is normally undertaken. A less comprehensive geological investigation may be undertaken during the conceptual design phase to assist the designer to assess, in broad terms the land requirements for a future road solution.

Where the scope of work includes a detailed geotechnical investigation, a broad evaluation of the terrain and site conditions to identify potential high risk areas is commonly undertaken. A more detailed geotechnical investigation would then be undertaken prior to construction to inform the detailed design requirements (e.g. an overpass instead of an underpass).

Assess ground response to changes

Once the site conditions have been established the response of the ground to changes should be assessed. This will generally involve in situ or laboratory testing and, importantly, research of case studies and previous experience in similar terrain. Engineering properties relevant to the proposed changes are assessed including the soil and rock stiffness, friction on discontinuities and hydraulic conductivity. The engineering properties that need to be assessed depend upon the proposed changes (e.g. increased or reduced loading) at a given location on the proposed road alignment.

Assess geological hazards

The ways in which the ground conditions could influence the design of a road should be assessed having regard to the type of hazard, the likelihood of its occurrence and likely consequences. Common geological hazards that should be considered by the designer include landslide, earthquake, expansive soils and limestone terrain. The likelihood and consequences of hazards may be assessed through desktop studies and geological mapping, but more commonly through previous experience of similar hazards (particularly if problems have been experienced with nearby projects).

The information obtained during the geotechnical investigation can be used by the designer to assess that a ground response is likely to be acceptable and geotechnical hazards are mitigated where appropriate. Detailed geotechnical design by an experienced geotechnical practitioner may be necessary to achieve the design objectives. Examples of design and other activities that require consideration of geotechnical information include:

- selection of road alignment and location of structures
- fixing the road profile, depth of cuttings, height of embankments and minimum batter slopes
- defining the new road reservation having regard to depth of cuttings, height of embankments, steepness of batter slopes and special drainage requirements
- determining the excavation characteristics and determining the means of excavation of materials in cuttings
- predicting the effects of seismic loadings upon cuttings, earthworks and structures
- determining the suitability of in situ materials for use as selected fill, capping material or pavement subbase
- selecting and designing the road pavement (refer to the *Guide to Pavement Technology Part 2: Pavement Structural Design* (Austroads 2017c))
- designing foundations for structures
- determining the requirements for and design of earth retaining structures
- designing subsurface drainage systems and special dewatering systems to intercept and direct ground water to the surface drainage systems
- determining the requirement for, and designing of, ground improvement works
- predicting the magnitude and rate of settlement of embankments
- assessing feasibility and producing cost estimates of alternatives.

Terms and definitions used in geotechnical investigations

There are a number of terms used in geotechnical investigations, many of which are contained in the *Austroads Glossary of* Terms (Austroads 2015). Some of the terms and their definitions, in addition to Austroads (2015), have been provided in Appendix B.1.5.

B.1.4 Safety During Investigations

In planning and undertaking any investigation, site and workplace health and safety requirements should be considered and the corresponding hazards/risk should be mitigated. A site risk assessment should be undertaken prior to commencing any works.

- Some of the issues which should be addressed may include, but are not restricted to:
- proximity to vehicular traffic
- accessibility and trafficability of the site

- presence of contaminated material
- stability of embankment slopes
- stability of trenching and need for shoring
- location of any utility services, including overhead powerlines
- probability of wall collapse arising from vibration or traffic movement
- working within confined space
- anticipated weather conditions.

B.1.5 Definitions

Table B 2 contains many of the terms and their definition used in geotechnical investigation and activities in Australia, many of which are also adopted in New Zealand, although there are some differences. Other terms and their definition can be found in the Austroads *Glossary of Terms* (Austroads 2015).

Table B 2: Definitions

Term	Definition
Acid sulphate soils (ASS)	Materials which contain iron sulphides in concentrations which have the potential to produce acidic conditions in the earthworks if left untreated. Acid sulphate soils include all materials which are actual acid sulphate soils or potential acid sulphate soils.
Assigned California Bearing Ratio (CBR)	The CBR assigned to a source or stockpile of earth fill material as determined by the appropriate test methods.
Assigned swell	The swell (%) assigned to a source or stockpile of earth fill material based on the values obtained from swell test values obtained in conjunction with the soaked CBR.
Backfill	Material placed in confined excavations for culverts, structures, conduits, pits, etc. or, in some instances, to fill excavations of unsuitable material. Backfill includes bedding material and materials placed in the foundation bedding, haunch, side and overlay zones during culvert backfill.
Bedding material	Material suitable for use in the foundation bedding zone of culverts and for bedding of pipes, conduits, pits.
Borrow area	An area: • on the site outside the excavation lines, or • an area off the site which can be developed as a source of borrow material.
Borrow material	Material, sourced from borrow areas, which is used to supplement a shortage of material sourced from excavations.
Confined earthworks	Any earthworks behind structures, in trenches, backfilling or repair works.
Confined excavation	An excavation for a culvert, pipe or conduit trench or an excavation for a structure which requires the use of an excavator or similar machine fitted with a bucket. An excavation is not classed as a confined excavation where the excavation is of sufficient size to allow the operation of a crawler tractor of Class 150C or larger.
Core zone	The central zone of an embankment.
Diversion channel	An open channel that diverts or redirects a given water flow from its natural flow path.
Drainage layer	A layer of permeable material placed within the subgrade in wet cuttings.
Earth backfill material	Earth fill material predominantly less than 25 mm stone size used as backfill.
Earth fill material	Fill material for an embankment that can be placed using the compacted layer method.
Fill material	Material making up an embankment, used to backfill subgrade treatments or to replace unsuitable material. Includes both earth fill and rock fill.
Foundation surface	The level of an excavation for a structure at which the material with the required bearing capacity exists.

Term	Definition
Free draining granular material	Coarse graded backfill material used behind retaining walls.
Haunch zone	The layer of material immediately above the foundation bedding zone for installation of pipe culverts.
Lot	An area of work that is essentially homogeneous in relation to material properties, moisture condition during compaction, rolling response and compaction technique, or a single finished item of work which includes several materials and/or work types (for example, a culvert in place).
Lot CBR	The CBR assigned to a Lot of untreated subgrade.
Lot expansive nature classification	The expansive nature classification assigned to the untreated subgrade material.
Lot swell	The swell (%) assigned to a Lot of untreated subgrade material based on the values obtained from swell test values obtained in conjunction with the soaked CBR test.
Monosulphidic black oozes	Monosulphidic black oozes are highly reactive organic-rich gels with extremely high moisture contents. They are commonly enriched in ultra-fine grained reactive iron sulphides.
Natural ground surface	The ground surface which exists prior to any work being carried out.
Overlay zone	The layer of material placed above pipe culverts.
Planting media	Material used as a planting medium for landscaping.
Prepared ground surface	The ground surface after clearing and grubbing and topsoil stripping operations have been completed.
Relative compaction	The ratio, expressed as a percentage, of the in situ density (wet or dry) of the material presented and the maximum density (dry or converted wet density) of a reference sample compacted in accordance with a specified procedure.
Road excavation	All excavation except for confined excavation and excavation for open channels and drains.
Rock fill	Fill material consisting predominantly of stones and rock. Stability is achieved by mechanical interlock.
Select backfill material	Backfill comprising gravel and/or loam materials with specified properties used for backfilling to trenches and structures.
Spoil	Material surplus to the requirements which is disposed of on or off the site.
Stabilised sand	Backfill material comprising sand stabilised with cement.
Stone	Material including natural rock, natural gravel, processed crushed rock and construction rubble which does not break down significantly under compaction.
Subgrade	The trimmed or prepared portion of the formation on which the pavement is constructed.
Subgrade level	The level of the top surface of the prepared subgrade on which a pavement is constructed.
Topsoil	The top layer of existing soil on the site which supports vegetation.
Treated subgrade	The subgrade in cuttings which has been either modified or replaced to improve its properties.
Unsuitable material	All material identified as unsuitable for use as a foundation for earthworks or structures and/or for use as fill or backfill material.
Untreated subgrade material	Natural unprocessed material that will form part of the subgrade, other than that moved from another location and/or compacted at the location. May include material placed and compacted as part of previous works, or material that is naturally occurring.

Source: Based on Queensland Department of Transport and Main Roads (2017) and Austroads (2015).

B.2 Overview of Geotechnical Investigations

Geotechnical information is produced at different levels of detail at various stages of the design process. The geotechnical investigation and road design processes are generally iterative starting with broadly defined information as a basis for initial design decisions, after which there may be successive refinements as detailed design proceeds.

Figure B 1 shows some of the factors to be considered in selecting an appropriate investigation method.

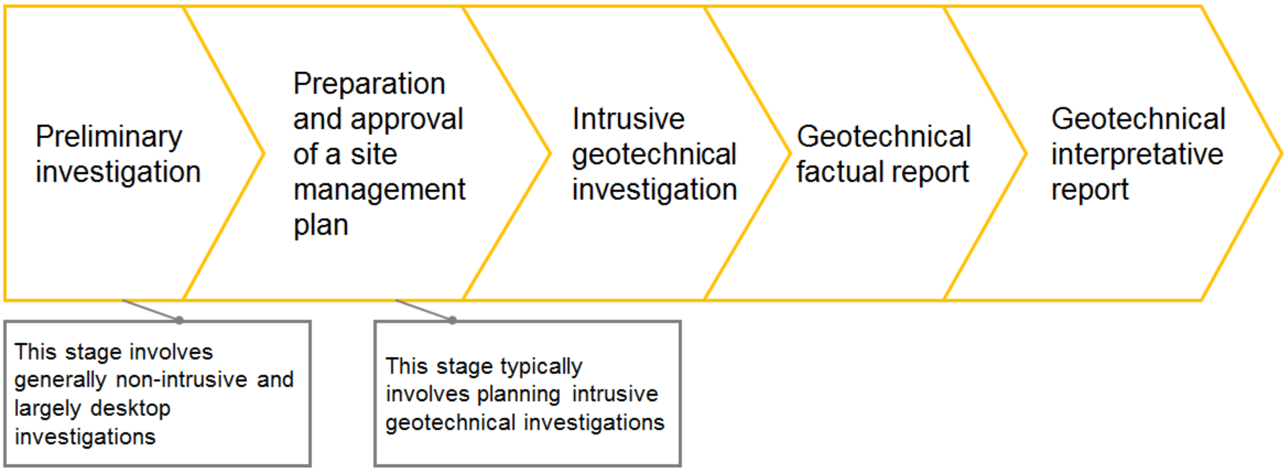
Figure B 1: Factors to be considered in selecting the investigation method

Input / Factors to be considered (not exhaustive)	Output
Objectives of the investigation	Geotechnical Investigation Method
Site conditions	
Available equipment	
Cost and time considerations	
Health, safety and environmental considerations	
Any regulatory requirements	

AS 1726:2017 provides information on geotechnical site investigation and the New Zealand Geotechnical Society has published a ground investigation specification (New Zealand Geotechnical Society Inc. 2017) providing information on the types and methods used for geotechnical tests.

Figure B 2 shows the main stages of a geotechnical investigation.

Figure B 2: Main stages of a geotechnical investigation



B.2.1 Preliminary Investigation

General

The project development phase (project scoping) is the process used to define the general requirements of a road project and to seek approval from stakeholders. A project is normally evaluated on three principal criteria comprising cost and economic benefits, community impacts, and environmental impacts. Geotechnical issues can influence each of these criteria.

Cost and economic benefits

The project cost is significantly influenced by geotechnical issues such as the volume and balance of earthworks, difficulty in excavating local materials (rock or soil), foundation conditions, supply of suitable road making materials, management of ground water, and stability of road cuttings and embankments.

Utility locations

Any field investigation should include identifying the location of utility assets. Disruption or damage to these assets can impact communities and be expensive to repair.

Community impacts

In the context of site conditions, issues of community concern can include such matters as ground vibration, noise, construction traffic, changes to ground water levels, water quality, local habitat, sustainability, visual appearance of batter slopes and dust generated during construction.

Environmental impacts

Environmental impacts include the identification and treatment of ground water, drainage, acid sulphate soils, erosion prone soils such as silt, buried landfill and waste dumps, and impacts of preventative or remedial treatments as necessary.

All of these design considerations require geotechnical information that should be sought prior to and during the project scoping phase. It is usual to undertake a preliminary geotechnical investigation or desktop assessment to obtain information that may be used to:

- produce conceptual drawings
- provide a sound basis for undertaking more detailed geotechnical investigations
- identify the type and extent of geotechnical investigations required at various locations.

Desktop assessment

Every site investigation will normally commence with a desktop assessment directed towards collecting, collating, and reviewing the available information. This is a relatively inexpensive activity which can reveal important information that can supplement, provide focus for, or even remove the need for, parts of the detailed investigation.

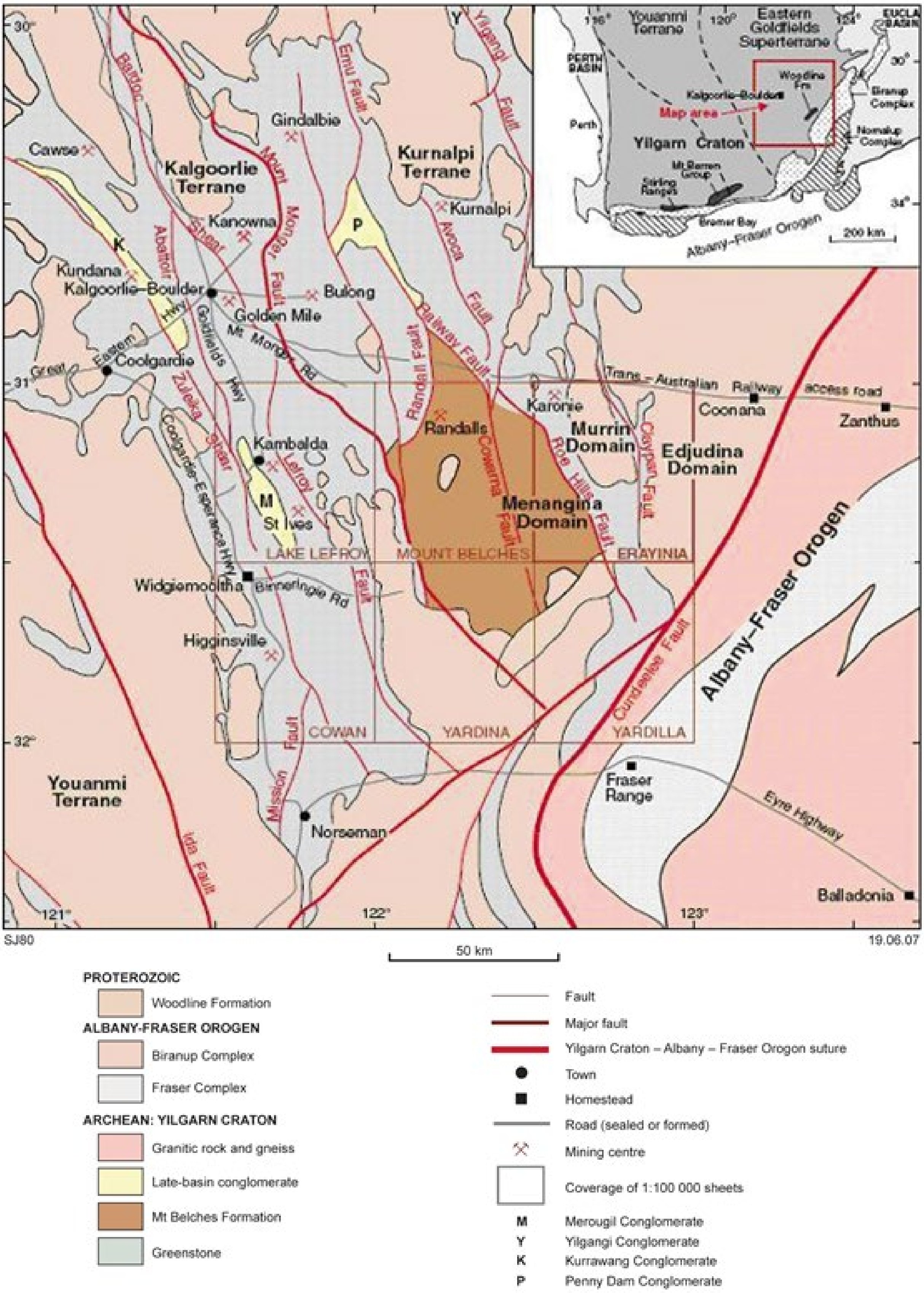
Examples of sources of readily available information include:

- Existing design drawings from work at or near the site showing longitudinal sections and cross-sections, subsurface drainage and other elements that were employed on nearby projects previous site investigation reports, borehole logs, penetrometer results and construction experience e.g. piling records, survey data and records that show rock and soils typically mapped at the ground surface.
- Geological maps. Most geological maps have accompanying notes which provide further detail on the materials indicated on the map. Figure B 3 and Figure B 4 show examples of geological maps.
- Topographic and geological maps that can provide useful information regarding subsurface materials and can also indicate such things as rock outcrops and high ground water levels (e.g. springs or swamps). Local government authorities may be able to provide this data through geographical information systems.
- Mining records that may be available in some areas and can provide information on the location of underground voids.
- Land stability mapping undertaken by some national and state/territory road agencies that shows the existence of land slips and unstable soil formations along existing roads. This information can be used to identify potentially unstable areas that may require flatter (or special) batter treatments.

- Hydrological data that can usually be obtained from local water authorities to assist with establishing ground water levels and water chemistry. Some government agencies also maintain information on ground water bores within an area.
- Identifying previous land ownership and land use. Previous land uses may impact on suitability of in situ materials for re-use and removal requirements, e.g. contaminated soils.
- Aerial photographs and satellite images can provide important information about the local geology and can also be useful in identifying changes that have occurred to the ground. Such changes may include the infilling of dams or quarries, erosion, landslip movement, demolition of structures, previous earthworks, and the impact of severe weather events such as a hurricane, see Figure B 5.
- Regional seismicity data can reveal the seismic potential in an area of interest. For further information see AS 1170.4:2007, *Structural Design Actions – Earthquake Actions in Australia*, or NZS 1170.5:2004, *Structural Design Actions: Part 5: Earthquake Actions: New Zealand* and the NZ Transport Agency *Bridge Manual* (NZ Transport Agency 2016).
- Geotechnical databases such as the *New Zealand Geotechnical Database* (NZGD n.d.) and the *Queensland Geotechnical Database* (Open Data Institute 2020).
- Erosion management overlay or similar reports that are produced by many local authorities and can provide information on the potential for erosion and landslides.
- Local knowledge and historical information from the local libraries or persons living or working in the area can provide an excellent source of published or anecdotal local information. Even a conversation with local road maintenance personnel can prove to be invaluable.

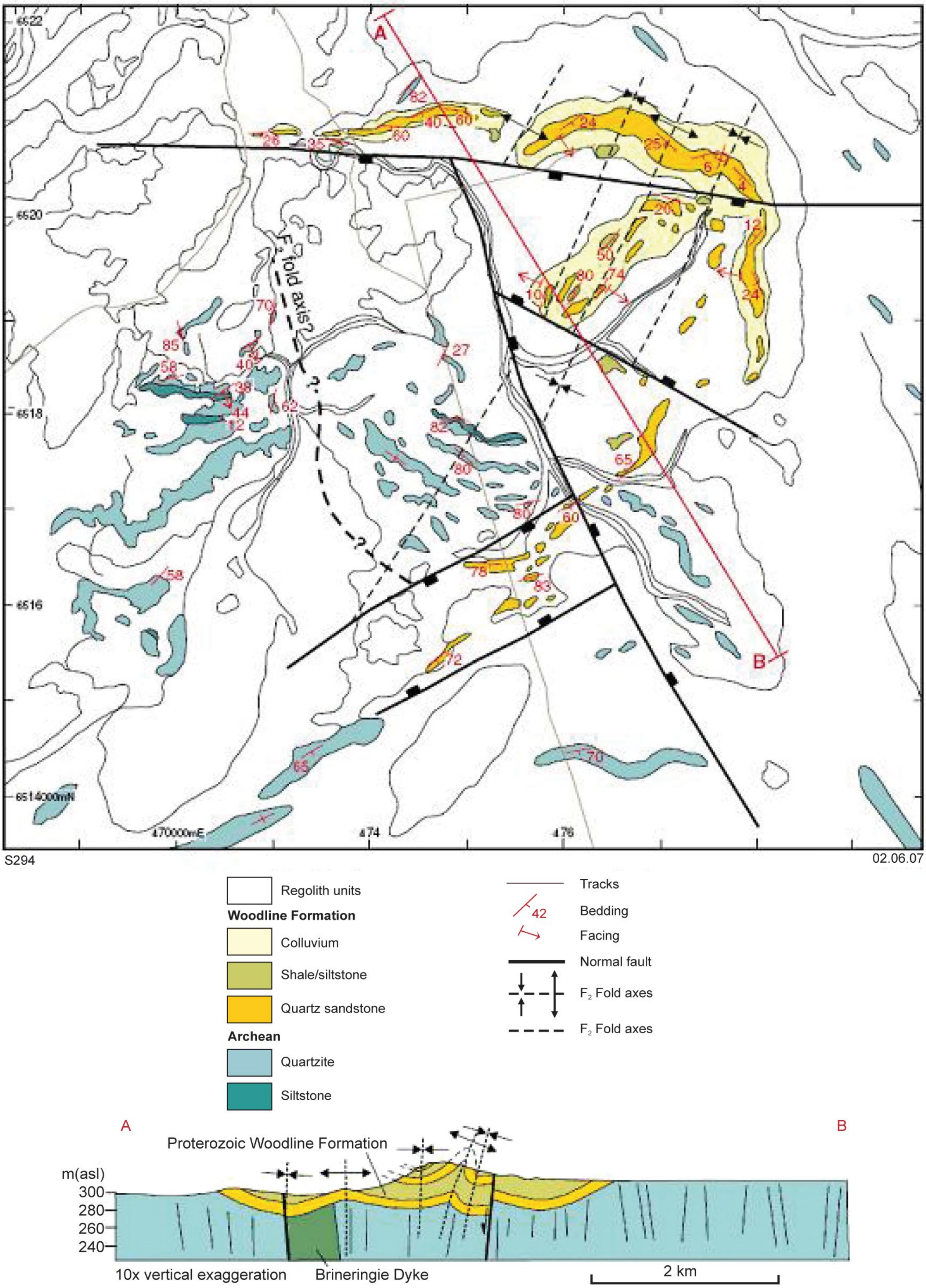
Where possible, the above information should be collected and collated prior to undertaking the field reconnaissance described earlier.

Figure B 3: Example of a locational and regional geological setting



Source: Image courtesy of the Geological Survey of Western Australia, Department of Mines, Industry Regulation and Safety. © State of Western Australia (2017).

Figure B 4: Example of a geological map and cross-section of a syncline



Source: Image courtesy of the Geological Survey of Western Australia, Department of Mines, Industry Regulation and Safety. © State of Western Australia (2017).

Figure B 5: Aerial photograph showing change in land after a hurricane

Source: U.S. Geological Survey (2016).

Field reconnaissance

Field reconnaissance involves a thorough visual examination of the site to provide further information on features identified in the desktop assessment and to potentially reveal features not identified during this assessment. Before a field reconnaissance is commenced, all the necessary permits must be obtained to enter private property for this purpose (see also Appendix B.2.2).

The features that may be observed and recorded during a site reconnaissance include:

- land form, rock outcrops, and rock or soil exposed in cuttings
- surface erosion
- proximity of existing structures and buildings
- mine workings or quarries either in current use or obsolete
- evidence of landslips or unstable soil conditions
- soil subsidence such as sink holes and any cracking or damage to existing structures

- ground water seepage and spring activity
- swampy areas that may contain silt or peat or other unusable material
- surface cracking indicating expansive soils or some other physical movement
- changes in vegetation growth indicating the presence of contaminated water either from chemical waste, dissolved salts or exposed acid sulphate soils
- industrial sites where contaminated soil may be present
- water level in rivers and streams and extent of tidal movement
- various soil types that are present
- various aspects of access to the site for a detailed geotechnical investigation requiring drilling and/or excavation
- the type of vegetation in the area which may indicate shallow ground water
- vehicle access points, clearances (horizontal and vertical) and load limits
- requirements for access tracks on soft ground
- water supply source and access arrangements
- traffic management requirements
- status of land acquisition of private property.

Contaminated sites require particular care when undertaking investigations and an example of a procedure is contained in VicRoads (2008). The local requirements should be sought from the road agency.

Preliminary geotechnical report

Information obtained from the desktop assessment and field reconnaissance is used to compile a preliminary report where potential geological hazards are identified and documented. This report should then form an important part of selecting a suitable road alignment and producing conceptual drawings.

B.2.2 Approvals for Site Investigations

Geotechnical fieldwork will typically involve intrusive investigation techniques such as boreholes, test pits and trenches and may require the construction of access tracks. The geotechnical investigation is therefore the first real evidence of construction activity noticed by the community and it is most important that all activities are undertaken in an environmentally sensitive manner. It would be expected that clearances to permit a geotechnical investigation would address the potential impacts those activities may have on flora and fauna, cultural heritage, surface water, ground water, noise, and vibration.

There are various laws, regulations and codes of practice operating in each jurisdiction governing activities that may result in disturbance to the environment and/or discharge of harmful substances, which may include the need for the preparation of a cultural and heritage management plan. These may all have a similar intent, but approval and operational requirements may vary between jurisdictions.

Geotechnical investigations may include activities that are generally regarded by environmental agencies as being similar to road construction activities. Prior approval to enter land, and to disturb parts of the site for the purposes of geotechnical investigation will therefore be required. Approval or licence from the local water management or supply authority is usually required to extract water from a stream or water storage for drilling purposes.

Prior to giving approval for work to commence environmental agencies may require a formalised environmental management plan to be produced for geotechnical investigations showing how all environmental hazards and potential impacts are to be addressed.

Where access to private property is required, the land owner should be fully informed of the nature of the work, the effects of that work on the property and its resulting condition after completion of the investigation. It is desirable that a representative of the geotechnical team is present when advice is being provided to land owners.

B.2.3 Detailed Geotechnical Investigation

General

Once the horizontal alignment is defined and conceptual drawings produced, there is often a delay before the project is approved for detailed design and construction. Conceptual drawings are usually developed to enable the new road reserve boundaries to be defined, cross-section and grade line to be notionally set, and areas of geotechnical uncertainty to be identified. There is usually more than sufficient detail in the conceptual drawings to assist the geotechnical engineer to refine the preliminary geotechnical information and provide further (and more detailed) information and advice about specific aspects of the proposed road project.

A detailed geotechnical investigation typically provides the types of information that is summarised below.

Development of a geotechnical model

A geotechnical model should be developed for geotechnical investigations. A geotechnical model may consist of a simple description of local geology based on existing information and some engineering characteristics of the project area. A model could also include geological maps and cross-sections showing strata likely to be encountered, and information on engineering characteristics of the soils and rocks and ground water levels.

More information on a geotechnical model can be found in AS 1726:2017.

Identification of potential risks

The risk posed to a road project from geological hazards may influence a number of design aspects including:

- requirements for slope support where the potential for natural landslides is identified
- determination of design seismic load for structures
- requirements for ground treatment/improvement where weak or unstable ground is identified
- choice of horizontal and vertical alignment to avoid geological hazards
- special treatments required for soils with a high swell potential, higher than permitted content of dissolved salts, acid sulphate reaction, liquefaction potential and any other identified hazards that may affect work safety and the environment.

Location and classification of rock and soil

Generally, the more that is known about site conditions the lower the geotechnical risk. The level of risk that is acceptable is project specific and detailed assessment of risks is beyond the scope of this guidance. The geotechnical information should provide the designer with a clear three dimensional picture (i.e. a conceptual model – refer to AS 1726:2017 for more information) of the surface and subsurface materials along the route and their basic properties and distribution. Intrusive investigation techniques such as boreholes, test pits, and trenching are the most common means by which this information is gathered.

Information is typically presented as a series of specific reports including supplementary data such as borehole logs and geological cross-sections preferably in a geographic information system format. The results of the investigation should clearly identify the four basic properties of the ground (i.e. material, mass, ground water and environmental properties) and, where appropriate, recommend solutions for the designer to consider.

For methods of describing soils and rocks in Australia, designers should refer to AS 1726:2017 and in New Zealand, to the Guidelines for the Field Classification and Description of Soil and Rock for Engineering Purposes (New Zealand Geotechnical Society Inc. 2005).

Rock excavation

Whether or not rock can be readily ripped and excavated by earthmoving plant without the use of explosives, may have a significant influence on the:

- choice of final horizontal alignment and elevation of the grade line (after geometric requirements are satisfied) to minimise expensive and difficult excavation and to avoid blasting if possible
- design of footings for structures
- suitability of ripped rock to form various layers within embankments, selected fill or capping material, structural fill or for use as pavement subbase material.

Strength and physical properties of soils and rock

The strength and physical properties of soils and rock are assessed by in situ and laboratory testing. Such properties may include:

- CBR, swell potential and in situ moisture content of materials intended for use at subgrade level or for use as selected subgrade fill or capping material
- undrained shear strength and effective stress properties of soils
- particle size distribution of all soils
- plasticity of cohesive soils
- rock mass strength
- relative density of soils
- uniaxial compressive strength of rock (refer to Appendix B.6.1)
- maximum density and optimum moisture content for all materials required for use in the road formation or as part of the pavement
- permeability of material to be used as a capping layer to be placed over expansive material
- the potential aggressiveness of soil and water samples to buried concrete and steel, evaluated through chemical testing
- coefficient of consolidation, coefficient of compressibility and modulus of elasticity for materials subject to a change in stress
- total and effective stress properties of soils
- other project specific parameters that may be recommended by the geotechnical expert or required by the designer.

These parameters may be used to determine the:

- location of areas prone to excessive settlement so that settlement monitoring processes can be initiated, and/or mitigation methods such as ground treatment or the removal and replacement of fill can be developed
- properties of materials that influence the selection and design of footings for structures
- stability of cut and fill batter slopes
- location of contaminated ground and identification of the means to mitigate associated hazards
- subgrade strength for the structural design of the pavements
- use of materials for embankment and pavement construction.

For information on methods of carrying out investigations, including drilling holes and pits, in situ testing, installation of instrumentation and sampling of materials refer to Appendix B.3.6.

Ground water

The presence, quality/chemical composition and regime quality of ground water has an influence on the:

- selection and design of subsurface drainage systems to intercept ground water, to lower the water table and to prevent the subgrade and road pavement from wetting-up both during and after construction (refer also to Section 8 in Austroads (2013c) and Cedergreen (1997))
- design of special systems to treat ground water that contains a higher than recommended amount of dissolved minerals and salts, prior to discharge into the surface drainage system and watercourses
- rate and amount of consolidation in locations where stress on the ground is increased, particularly where embankments are to be constructed over soft and/or saturated soils
- design of stable batter slopes
- selection and design of soil nails
- footing design
- liquefaction susceptibility.

Contaminated soils and water

The presence, quantity and quality of contaminated soil and ground water should be assessed so that treatments meeting the legislative requirements can be designed.

Identification of areas for borrow material

Investigation of suitable areas for borrow material on projects where there is a shortfall of cut to fill may require an intrusive investigation at a location some distance from the project site. Investigations of borrow areas usually require boreholes and test pits in conjunction with laboratory testing unless the material comes from a known source such as a quarry site. The location of a borrow area has an influence on the:

- cost and environmental impact of haulage if the borrow area is remote from fill embankments
- ease of access to and from the borrow area for hauliers
- impact on the local road system from haulage of large quantities of borrow material where use of local roads is the only means of access
- engineering properties of the borrow material
- standard of restoration required for the borrow area.

B.2.4 Design of Special Systems

During the design phase the designer may encounter difficulties in balancing the needs of the design with respect to the terrain characteristics. Special treatments and systems requiring a geotechnical design may be required:

- to stabilise cut or fill batters by techniques such as soil nailing, sprayed concrete, rock anchors, reinforced earth and gabion walls (for examples of treatments refer to Appendix B.7.2).
- to intercept subsurface water using treatments such as deep formation drains, filter blankets, and ground water purification or retention systems
- to dewater low-lying areas using methods such as wick drains, geotextile matting or mattresses, drainage blankets
- when using lightweight fill incorporating polystyrene blocks, and other special rafting or piling methods
- when determining embankment loading on soft materials
- to minimise soil erosion by the use of geotextile matting, drop structures, retarding basins, batter stabilisation, and various types of channel lining systems
- to treat and discharge ground water containing a higher proportion of dissolved salt than permitted by the environment protection agency.

The designer should consult with a geotechnical expert for advice on how best to address such difficulties to suit the circumstances of the project and local environment.

B.2.5 Production of Geotechnical Reports

General

Road agencies may have guidelines on the structure and information to be provided in a geotechnical report. Geotechnical reports are generally either a geotechnical data report or a geotechnical interpretative report. These reports may be produced as a single report or two standalone reports. In New Zealand these reports are produced as separate standalone reports.

There are four main classifications for information covered in a geotechnical report. These are:

1. Facts

The facts given in a geotechnical report include such matters as site observations, borehole logs, photographs, laboratory test results, ground water levels and any other information that has been measured or surveyed.

2. Interpretation

The interpretation of the facts can be provided by specialist engineering geologists or geotechnical engineers to give meaning to factual information such as classification and suitability of materials for various uses and the production of geological strata boundaries interpolated between borehole logs or from seismic information.

3. Opinions

The opinions from engineering geologists and geotechnical engineers can suggest, for example whether or not a certain material is considered capable of being ripped with a large dozer based on seismic velocities. An opinion may be expressed as to whether a certain type of gravel is suitable for use as a pavement base course.

Opinions must only be given by those who have the skills, knowledge and experience to provide such advice.

4. Hypothesising

To aid the production of conceptual drawings a geotechnical specialist may occasionally be required to hypothesise on preliminary geotechnical information if there are insufficient facts to carry out an interpretation or form an opinion.

Hypothesising should never be included in a geotechnical report that will be used as a basis for a final design or for undertaking construction works.

Generally, all relevant factual information should be made available to tenderers however, if there is a reason for any outlying or non-typical test results, it should be stated. Whether matters of interpretation or opinion are made available should be determined on the merits of each individual case and these are generally referred to contractual experts for advice.

The principal objectives in supplying information to:

- provide greater certainty in estimating costs
- reduce risks if unforeseen conditions are encountered and thereby minimise the occurrence of delays and disputes.

These objectives can be achieved by ensuring that:

- factual information is accurate and sufficiently comprehensive for the scale of the project
- any interpretations in regard to the variability of site conditions are soundly based
- opinions are provided by qualified and experienced persons.

In practice, most of the information provided in a geotechnical report is targeted toward certain design objectives rather than as open-ended information. Where this is the case it will be necessary to add a qualification to the information.

Geotechnical data report

A geotechnical data report provides factual site information obtained from the data collected, including presentation of details of all field and laboratory test data including photographs. In New Zealand, this report is known as a geotechnical factual report.

Geotechnical data reports are generally provided for most road construction projects. Typically, they would address on-site conditions, foundation materials, borrow materials, subgrade materials and pavement materials. Some road agencies also require the inclusion of information about water bores, rainfall and river flows. If the designer is responsible for preparing a brief for a geotechnical report it is important that work is properly defined and the standard expected for the geotechnical data report is covered by the brief. Many road agencies have standardised briefs for geotechnical investigations.

The structure and content of a geotechnical data report varies with the size and complexity of the project. However, a typical standardised format is likely to have the structure, topics, and content described below.

Introduction

- purpose, scope and objectives of the investigation
- brief description of the project covering location, geometry, structural elements and materials
- dates (e.g. when field and laboratory testing was undertaken).

Description of site

- geographical description of location including street and road names and a mapping grid of global positioning system references
- current land usage and/or previous usage if relevant, particularly the location of any landfill sites and areas of historical interest
- description of topographical features.

Geological description

- geological description of the site and sources of information
- details of any previous geotechnical investigations undertaken in the area.

Field investigation

- description of methods used and standards followed and the rationale for adopting a certain frequency or spacing of bore holes, excavations and number of samples extracted for laboratory testing
- type, make and model of machines and field equipment used
- field observations made during site inspection and field work such as areas of instability, faulting, details of exposed soil or rock strata in quarried or borrow areas, settlement of nearby structures, presence of ground water, difficulty of excavation and information provided by people either living or working in the area
- a description of the methodology, standard and scope of field testing including an account of any site restraints encountered
- fluctuations in ground water in boreholes during performance of the field work and in piezometers after completion of field work.

Laboratory testing

- description of sampling procedures used for laboratory tests undertaken on soil and rock samples
- reference to standard test methods followed
- inclusion of NATA endorsed laboratory test reports for all tests undertaken
- tabulation of a summary of all test results.

Results of field investigation and laboratory tests

- compilation and presentation of field and laboratory test results in a logical sequence using diagrams and tables where possible
- description of the types and variability of materials encountered in each proposed cutting, foundations area, and the variability of materials, in situ California Bearing Ratio (CBR) of materials at or near subgrade level, location of any soft, wet or unstable areas
- characteristics and properties of the various materials encountered by coring and test pit excavation.

Appendices

- details of technical information such as bore hole logging sheets, colour photographs of extracted cores, laboratory test reports, cone penetrometer test (CPT) plots and seismic profiles (these are normally included in appendices)
- photographic and mapping records of the location.

Drawings

- conceptual drawings showing the proposed horizontal alignment, vertical alignment, major structures and selected cross-sections in deep cuttings to show the location (i.e. co-ordinates and chainage/offsets) and level of all bores, CPT sites, test pits and piezometers.

Note that in New Zealand, the contents of geotechnical factual reports are outlined in the *New Zealand Ground Investigation Specification: Volume 1: Master Specification* (NZ Transport Agency 2017).

Geotechnical interpretative report

The geotechnical interpretative report provides a geotechnical evaluation, interpretation, and any recommendations necessary to deal with geotechnical risks such as predicted settlement, batter slopes (refer also to Austroads 2020a), recommended design changes, and suitability of materials for road construction. It also may identify where further investigation should be considered to reduce potential design and construction risks.

A typical geotechnical interpretative report contains two sections – discussion and recommendations.

Discussion

Discussion under various headings may include:

- an executive summary outlining all critical points of the investigation, including identification of risks and mitigation strategies
- a geotechnical model appropriate for the proposed project, including longitudinal sections, showing test pits, correlations of pavement layers, ground water, and laboratory test results
- the completeness and reliability of field and laboratory data obtained and identification of data that may not necessarily fully represent the situation likely to be encountered
- the suitability of materials in proposed cuttings for use as fill, capping and pavement subbase
- stability of batter slopes in cuttings and desirable batter slopes for cuttings and embankments to minimise soil erosion
- geotechnical risks associated with the extent of field and laboratory testing undertaken, and the identification of locations where further geotechnical investigation should be undertaken if risks appear to be unacceptably high
- likely rock and soil profiles in cuttings or other proposed excavations shown on longitudinal sections and selected cross-sections
- extent of topsoil and unsuitable ground
- extent of weak or compressible foundation soil
- seismic loading appropriate to the site
- liquefaction and clay softening susceptibility to seismic loading of foundation soil
- excavatability issues for areas of cut and excavation, including advice on methodology that may be used to deal with excavation of rock that cannot be excavated by ripping and methods of breaking down and disposing of large boulders
- re-use potential of excavated material
- likely profiles of ground water and the identification of where special subsurface drainage systems such as deep formation drains and filter blankets will be needed
- identification of elements or locations along the project where additional geotechnical designs are considered necessary such as those listed in Appendix B.7

- comments in relation to the design profile, especially where the pavement may be adversely affected by the ingress of water
- identification of locations where there are expansive soils that will require removal or provision of a capping layer
- identification of locations where unsuitable materials, or unstable areas may cause construction difficulties, or require special treatments such as geotextile separation layers or dewatering systems, or require removal and replacement of soft areas and unsuitable materials with satisfactory material
- assignment of appropriate CBR for common fill, capping layer material and materials at subgrade level in cuttings
- geotechnical risks to be considered by the designer.

Recommendations

Recommendations may include:

- details of any further geotechnical investigation work required to minimise risks
- CBR for subgrade materials for use in the structural design of pavements
- seismic design parameters
- liquefaction mitigation methods
- special geotechnical treatments likely to be required
- maximum and desirable batter slopes for cuttings and embankments.

B.2.6 Emerging Technologies

New methods are emerging to enhance the surveillance and inspection of embankments and other locations where access is difficult. Unmanned aerial vehicles are being utilised to undertake surveillance of difficult access sites to monitor embankment face movements or slope stability.

Any restrictions on the use of these types of surveillance methods should be assessed prior to their use.

B.3 Methods of Geotechnical Investigation

This section outlines some of the typical site investigation methods that are employed to provide an indication of material properties. Some of the methods involve collection of samples of soil, rock, and ground water during the site investigation for laboratory testing to accurately assess their characteristics.

Designers should also refer to AS 1726:2017 for information on testing methods. In New Zealand, the *New Zealand Ground Investigation Specification: Volume 1: Master Specification* (NZ Transport Agency 2017) provides details that supplement/amend the sections described below.

B.3.1 Seismic Surveys

A seismic refraction survey measures the velocity of sound or vibration through the earth from an impact source. The impact may be generated by an impact hammer or a small charge of explosive. Seismic methods of exploration are based on the fact that shock waves travel at different velocities though different types of material. Transmission of sound vibration through solid massive rock is more rapid than for soft, fractured and weathered rock. Velocity readings are plotted on longitudinal sections and cross-sections to provide sound velocity contours indicating the location of different materials. Seismic survey information is generally supplemented with coring to classify rock types and their condition, and to assist with the determination of dip and strike (angle of bedding planes both horizontally and vertically) leading to an assessment of stable cut batter slopes, foundation conditions, etc.

B.3.2 Auger and Bore Holes

Drilling or coring is one of the most common field investigation methods used to obtain rock or soil samples for testing, and to establish the ground profile. An auger is typically used to bore through soft friable soils and highly weathered rock. Material removed by the auger is periodically sampled and logged, particularly at changes in soil type. Once the auger reaches rock, a core drill is commonly used to recover cylindrical samples of rock which are retained in core racks (Figure B 6) for subsequent photographing, classification and strength testing.

In cuttings, sufficient cores must be extracted to enable a reliable assessment to be made of the strength, depth and the dip and strike6 of soil and rock strata. Core drilling typically extends to at least 1.5 m below the proposed subgrade level, or more if there is a likelihood that the preliminary grade line will be lowered during the detailed design phase. It is essential to measure the ground water level in the borehole, particularly after the hole has been allowed to stand for some time, e.g. before commencing drilling each day, when water is first encountered in the borehole, at various time intervals after the core has been extracted and in piezometers. If ground water is not encountered in a hole, this should also be stated on the borehole log.

Figure B 6: Typical core rack

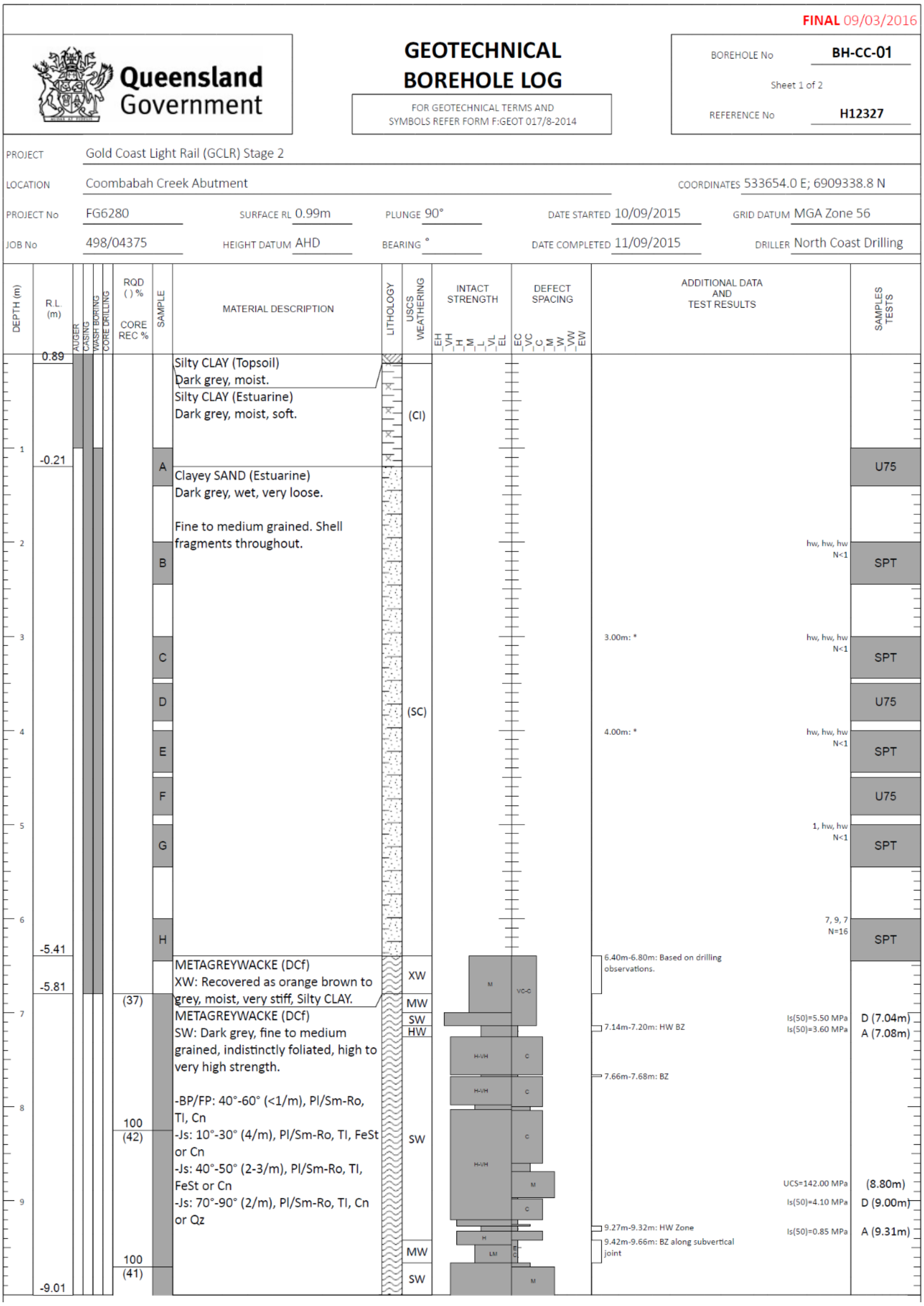
Source: AMC Consultants.

In planning and undertaking an investigation of soil or rock, jurisdictional standards or requirements should be considered.

Borehole logs (Figure B 7) are produced and some of these may be used to plot soil/rock strata against the proposed road longitudinal section and cross-sections. Drilled cores, in addition to disturbed samples are typically retained for a number of years after completion of construction.

6 Dip and strike describe the orientation of the layers of material. Dip describes the angle of tilt, measured from a horizontal plane and strike is the direction of the level a level line on the tilted surface. The strike is perpendicular to the direction of the dip.

Figure B 7: Example of a borehole log



Source: Queensland Department of Transport and Main Roads (2018).

B.3.3 Penetrometer Testing

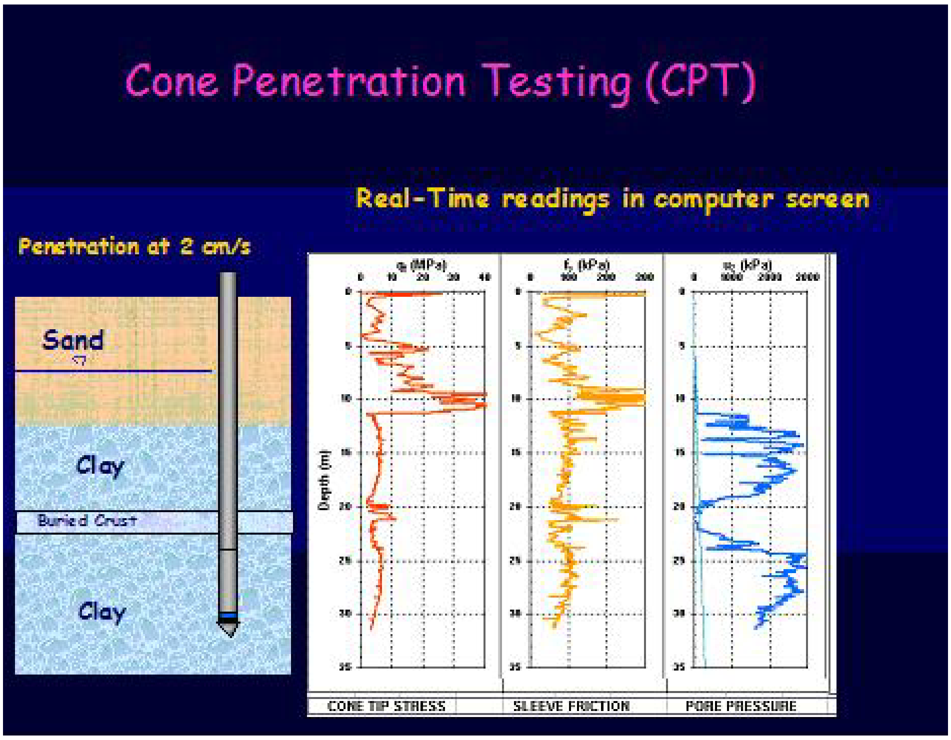
The standard penetration test involves the determination of resistance of soils to the penetration of a sampler, used to obtain a sample of the material. The tests involve a hammer falling freely from a fixed height to drive a split tube sampler into the bottom of a borehole. The values reported on the borehole logs are the blows required to advance three successive 150 mm increments. The first increment is a seating operation and is not considered in the engineering evaluation of the soils. The sum of the number of blows for the last two increments is the standard penetration resistance, known as the *N* value, indicating soil in situ strength and density.

A cone penetration test (CPT) device consists of a cylindrical probe with a cone-shaped tip with different sensors that allow real time continuous measurement of cone end resistance, sleeve friction and usually the pore pressure developed by the cone as it advances into the ground (the dynamic pore pressure). A typical output is illustrated in Figure B 8. The continuous profiles obtained from the CPT allow the geotechnical expert to visualise the stratigraphy, evaluate the soil type, estimate soil parameters, and to design shallow and deep footings subject to vertical load. The CPT is suitable for clays, silts, sands and some gravels. Depending on the thrust available, the test is generally not suitable for relatively stiff clays or dense sands. CPT outputs should be accompanied by a cone calibration certificate.

The dynamic cone penetrometer (DCP) (Figure B 9) measures the soil density or consistency. This DCP test is particularly useful for investigating the variation in subgrade strength with depth. The penetrometer is driven into the ground by raising the hammer and allowing it to fall freely onto the anvil. The relationship between the penetration and number of blows is determined and an in situ CBR determined from a CBR chart (Figure B 10).

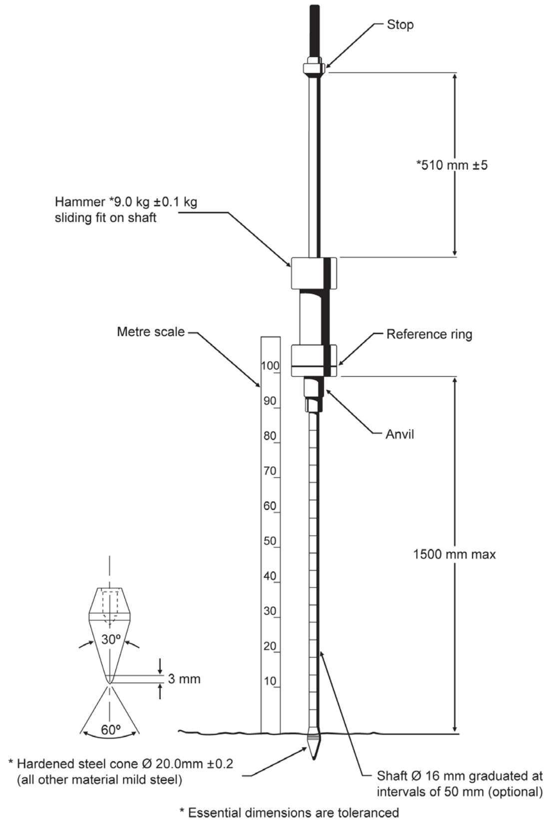
The in situ penetration resistance of fine-grained cohesive soils determined by DCP is related to the CBR value by means of the relationship given in Austroads (2017d), and NZS 4402:1988) and shown in Figure B 10. The correlation is not suitable for use with non-cohesive soils. The use of DCP should be restricted to fine-grained soils to avoid misleading results due to the influence of rock or gravel.

Figure B 8: Example output from the cone penetration test



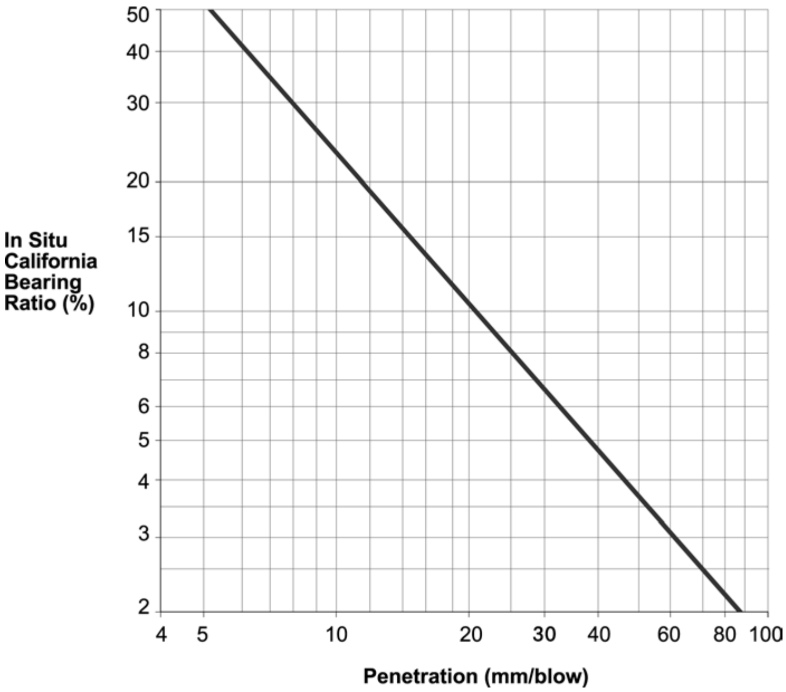
Source: Main Roads Western Australia.

Figure B 9: Schematic of the dynamic cone penetrometer



Source: Main Roads Western Australia.

Figure B 10: California bearing ratio (CBR) chart



Source: Austroads (2017d).

B.3.4 Standpipe Piezometers

Standpipe piezometers are used to measure ground water elevations. The information is required for most geotechnical analysis and design and can be used for:

- ground water quality testing (e.g. for dissolved salts)
- hydrogeological analysis to assess the effects of changes to the ground water table on local amenity
- environmental considerations such as the disposal of low quality ground water in accordance with guidelines produced by the environmental protection agency
- assessing the requirement for drainage blankets or other forms of ground water management.

Standpipes installed some years in advance of design and construction may be used to verify ground water level fluctuations between seasons and over successive years. Figure B 11 illustrates a typical piezometer tube and Figure B 12 shows how piezometers are used to determine a profile of ground water pressures.

An example of how ground water can be sampled from bores in more detail can be found in VicRoads (2007).

Figure B 11: Typical piezometer tube

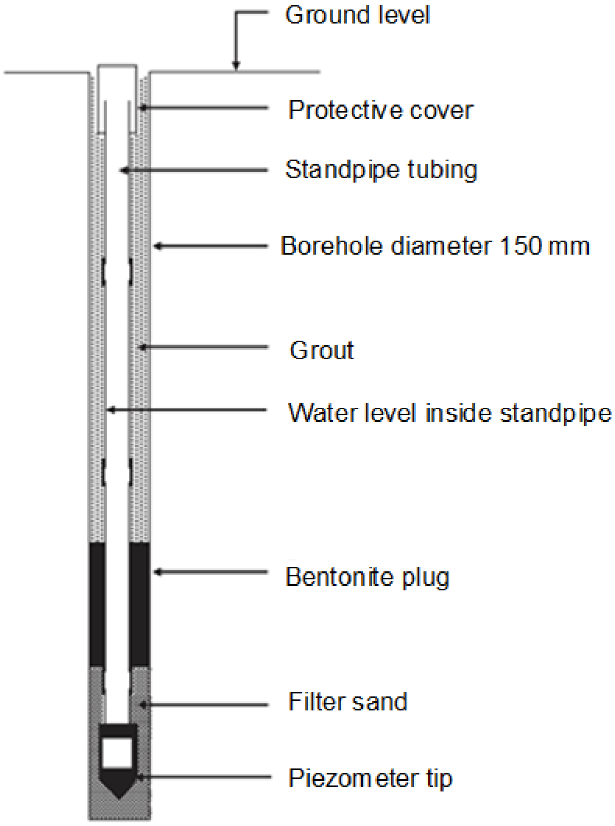
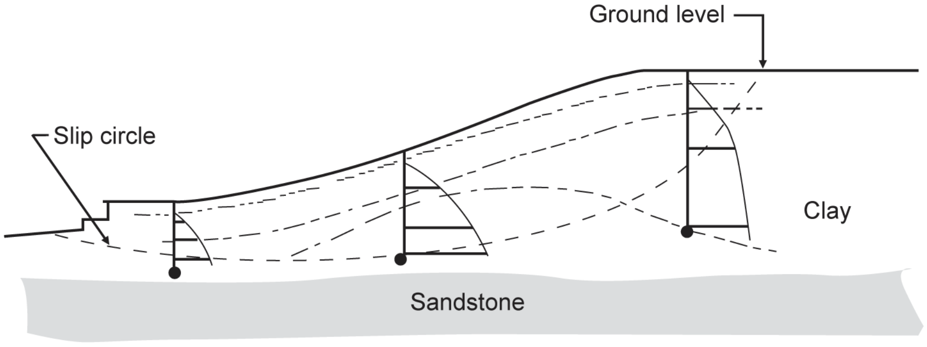
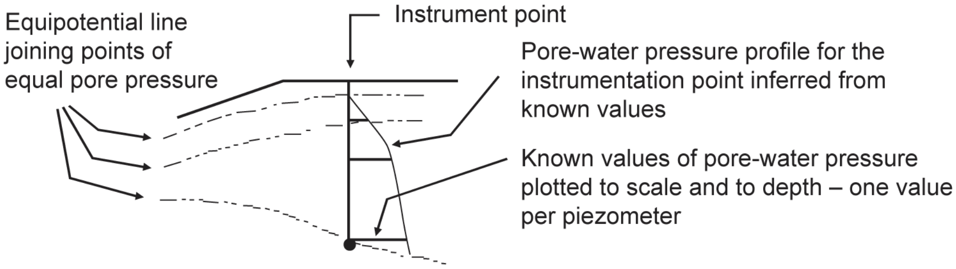


Figure B 12: Use of piezometers to establish ground water pressure profiles



(a) Profile of installation of piezometers



(b) Key to diagram of profile in (a)

B.3.5 Trenching

Test pits or trenches provide an economical method of undertaking an on-site examination of near-surface deposits and collecting bulk samples for laboratory testing. The different horizons in a soil profile can be observed in the vertical faces of the trench or pit allowing a complete assessment of the nature of the material. Trenching is also used to obtain additional information to support drilling and seismic refraction surveys. For large projects trenching may be undertaken to provide a profile of the material.

Test pits (including trenches) should be logged and include information relating to the time required to excavate the trench, trench dimensions, stability of the pit walls, ground water entry (or absence), descriptions of the in situ and excavated materials and good quality colour photographs of the trench and excavated materials. Information derived from test pits may be used for:

- assessment of whether or not rock is capable of being ripped
- sampling of in situ material for assessment
- producing a map of rock formations (e.g. dip and strike, faults, etc.)
- stability assessment of cut batter slopes
- assessing the suitability of material for fill
- determining the presence and amount of ground water.

Figure B 13 shows a typical open trench investigation and recording of soil layers.

Figure B 13: Open trench investigation and test pit

Source: Main Roads Western Australia.

B.3.6 Sampling and Testing of Materials

Techniques for sampling of materials and the minimum number and size of samples required to provide a reliable assessment of likely performance for the various test methods are specified in AS 1289:2017 (set). All field logging and sampling is normally undertaken by a suitably trained and experienced geotechnical engineer, engineering geologist or soil technician.

General

Laboratory testing should be carried out as part of the geotechnical site investigation in order to characterise the engineering and physical properties of materials that are likely to be encountered and/or modified by the road project under consideration.

The test methods that apply to soil testing are generally covered by Australian and New Zealand standard test methods. AS 1289:2017 (set) is used for the testing of soils and AS 1141:2017 (set) is used for the testing of aggregates. Similarly, NZS 4402:1988 (set) is used for the testing of soils and NZS 4407:2015 is used for the testing of aggregates. In New Zealand the *Guideline for the Field Classification and Description of Soil and Rock for Engineering Purposes* (New Zealand Geotechnical Society Inc. 2005) is used for descriptions of soil and rock. Variations to these methods or alternative test methods may be developed by road agencies and the local requirements should be confirmed with the road agency.

The National Association of Testing Authorities (NATA) has an accreditation procedure for the laboratory facilities and calibration of testing equipment. It is important when receiving test results that the test report makes a clear reference to NATA accreditation and is signed by a testing officer who has the appropriate accreditation.

Test properties

Some of the key properties of soils and rock are discussed below:

Density

The density of a material can be influenced by:

- compaction – the use of heavy static or vibrating compaction equipment over a relatively short construction period
- consolidation (or settlement) – the natural densification of a soil brought about by exposing it to a long term static load such as a fill embankment. Consolidation is generally brought about by air and pore water being slowly squeezed out of a soil under sustained static loading.

Strength of materials

The strength (compression or shear strength) are common engineering properties of a rock or soil material.

The strength of rock depends on a number of factors such its nature and geological classification, the number and location of discontinuities in the rock structure, the angle and friction between bedding planes and the degree of decomposition by weathering and moisture effects.

The strength of a soil also depends on a number of factors such as the density achieved by compaction or consolidation, the confining pressure, the particle size distribution (grading), the internal friction or angularity of soil and rock particles, and the moisture content.

Permeability

The permeability of a material is its ability to transmit or prevent transmission of water. The permeability decreases as the density and clay content increases. The permeability is used to specify the porosity of filter materials and resistance to transmission of water as applied to a capping layer or the pavement base material.

Physical properties (soil and rock)

Physical properties of a material are those used to characterise it. These include such properties as particle size distribution (grading), Californian Bearing Ratio (CBR), maximum dry density (MDD), plasticity index (PI), optimum moisture content (OMC), and various chemical properties.

Refer to Appendix B.6 for details of individual tests and their purpose.

Water quality

It may be important that chemical and conductivity testing is undertaken of all ground water proposed to be diverted into the surface drainage system, watercourses, estuaries and streams within or crossing the project boundaries. Dissolved salts can be highly corrosive for steel and reinforced concrete structures (culverts and bridges) and if discharged into fresh water can kill marine life and vegetation. If water with dissolved salts exceeding 3000 mg/litre is used for watering of construction work it can result in the formation of salt crystals that can cause bituminous surfacing to bubble and lift off the pavement base.

More information on the test properties can be found in the *Guide to Pavement Technology Part 4I: Earthworks Materials* (Austroads 2009a).

B.4 Design Elements

B.4.1 General

The horizontal alignment is considered in conjunction with the vertical alignment and cross-section to develop a design line that meets geometric requirements and satisfies major controls on the location of the alignment.

Geotechnical information should influence the initial and final choice of the road alignment, profile, and cross-section. It is not good practice to complete a geometric design without considering the limitations and advantages provided by the local terrain and site conditions.

Where a road reservation is yet to be defined it is appropriate to choose an alignment that achieves an economical and direct route with adjustment as necessary to avoid excessive rock excavation and poor foundation conditions, and to minimise stream crossings. In urban areas, the horizontal alignment will generally be confined to a previously defined road reservation with abutting urban development, and therefore alignment choices will be limited.

The alignment of a road project is usually developed incrementally. Initially, there may be a number of completely different alignment options such as two or more alternative bypass alignments on opposite sides of a town. Choices between these widely differing alternative alignments may in part be made on information obtained from the preliminary geotechnical investigation although there may be some overriding factors such as abutting property development, travel distance, and planning requirements. There may also be various environmental issues such as intrusion into sensitive areas (e.g. adverse effect on flora and fauna), visual intrusion or noise levels.

Once a single route is chosen, a more detailed geotechnical investigation is undertaken after which adjustments may be made to the alignment to optimise project costs and to deal with important community concerns and environmental issues.

B.4.2 Horizontal Alignment

Rural areas

In rural areas, the horizontal alignment is usually influenced by the type of terrain. Terrain can vary from flat to undulating (may involve river flats and swampy areas), undulating to hilly or mountainous terrain.

Flat to undulating terrain

Where the horizontal alignment is to be located in flat to undulating terrain there is a likelihood of poor foundation conditions and the presence of silt (unsuitable as a subgrade or fill material). It may be prudent to shift the alignment to avoid low-lying wet areas to achieve drier subgrade conditions during wetter times of the year.

Undulating to hilly terrain

The alignment in undulating to hilly terrain may be influenced by geotechnical information such as:

- the location of massive rock requiring extensive blasting
- minimum or desirable batter slopes for fixing the limits of earthworks, used to assess whether work can generally be contained within the road or planning reservation or to define an amended road or planning reservation boundary in order to seek subsequent land acquisition
- foundation conditions for large culverts and structures which may become control points on the horizontal alignment
- locations where there may be excessive lowering of the water table resulting in batter instability or settlement of adjacent land.

Mountainous terrain

In addition to the factors influencing the alignment in undulating to hilly terrain, geotechnical aspects that may also have an influence in mountainous terrain include:

- location of areas prone to land slips
- information to enable alignment options to be compared (e.g. very deep cuttings and high embankments compared to tunnelling and/or elevated structures).

Horizontal alignment in urban areas

In urban areas roadworks are generally confined to a road reservation in all types of terrain and only minor changes in horizontal alignment may be possible and geotechnical information may assist a designer to:

- determine the best alignment to minimise the height and type of retaining and noise walls
- vary the alignment of structures to avoid poor foundation conditions
- vary the alignment of proposed tunnels depending on the nature and stability of soil and rock formations.

B.4.3 Vertical Alignment

General

Once an alignment has been selected that satisfies geometric requirements for the grade line (e.g. minimum elevation above natural surface; desirable maximum grades) and control points such as the level of major structures, flood levels, intersections and rail crossings, other sections of the grade line may be adjusted within the geometric limitations to minimise geotechnical risks or cost. For example, it may be desirable to raise the grade line to avoid rock excavation or to provide a higher embankment over soft, wet or unstable areas.

Balancing of earthworks volume

Once a grade line is selected that satisfies geometric requirements it may be raised or lowered between control points to achieve a better balance between the volume of cut and the volume of fill (i.e. earthworks balance). If an earthworks balance is not achieved it is necessary to either import material from elsewhere to make up a short fall or dispose of surplus fill which may be difficult in urban or environmentally sensitive areas.

The in situ density of solid rock typically ranges from 2.6 to 2.9 t/m^3 but when crushed to provide fill, the density reduces to within the range of 2.0 to 2.4 t/m^3. This means that solid rock cut excavation will produce a 15% to 25% increase in volume (bulking) as compacted filling depending on the type of rock. If a cutting contains about 50% rock and 50% soil and is thoroughly mixed prior to compaction the volume of cut material may only exceed the volume of filling by about 10%.

Sands and gravels are about the same volume in cutting as in compacted filling however for expansive clays the compacted density can be higher than the in situ cut density resulting in a loss in volume from cut to fill.

With cut to fill earthworks some allowance must be made for wastage due to spillage, wet weather (e.g. cutting of wet material to waste) and disposal of oversize rock. Wastage can vary between 5% and 15% depending on the topography (more wastage is experienced in hilly country) and the content of large particles of blasted rock excavated material.

The slope of batters also has an influence on the level of the grade line required to achieve an earthworks balance. The comparison in cost of achieving an earthworks balance by raising the grade line and providing steeper batter slopes in rock cuttings to reduce cut volume and/or lowering the grade line and flattening batters in relatively low strength rock or soil cuttings to increase cut volume needs to be considered. Rock excavation requiring blasting and loading into dump trucks is significantly more expensive than excavation of materials that are capable of being ripped and transported in scrapers.

For an earthworks balance, it is important that allowance is made for the backfill of excavations associated with the removal of topsoil and unsuitable material such as silt, peat, vegetable matter, and isolated large boulders.

Broken rock placed in fill has a lower density than massive rock deposits and this can create a gain in volume of material available for disposal. Where massive rock excavation is to be undertaken, it is good practice to identify areas such as sound mounding and fill batter flattening where rock boulders too large to be placed as common fill can be buried as low grade non-structural fill.

Where an earthworks balance cannot be readily achieved and there remains a shortfall of fill, a ready supply must be made available from either borrow areas or from another project or from commercial sources such as a local quarry, sand pit or gravel pit.

Disposal of surplus fill

If there is excess fill as a result of an imbalance in earthworks it is desirable that it be disposed of within the road reservation by batter flattening, sound mounding or landscaping. The ability to undertake this work depends on the area available and the nature of the excess material. Boulders too large for narrow batter flattening or sound mounds are generally buried, removed to a crushing plant or split with rock hammers or explosives for use in embankments. The amount of unsuitable fill needs to be quantified.

B.4.4 Cuttings

The ground conditions within cuttings and borrow areas are assessed from the geotechnical investigation. Information on ground conditions is required to:

- indicate the ease of excavation
- design stable batter slopes
- design special drainage systems for ground water
- assess the quality of excavated material for use in embankments
- assess the quality of material and its suitability as structural fill, capping layer material and/or pavement sub-base
- determine the depth of topsoil stripping required to expose suitable materials that are essentially free from organic material.

Presence of rock

General considerations

The location of rock may have an influence on the horizontal and vertical alignment of a road. Excavation of rock that requires blasting is slow and expensive and it may be possible to avoid rock excavation requiring use of explosives by raising the grade line, particularly if softer material can be obtained elsewhere on the project by flattening cut batters or from convenient borrow areas.

The extent of rock excavation in the geotechnical data report is needed in order to:

- avoid or reduce the likelihood of prolonged delays and construction issues
- inform the planning and design of the project. For example, oversize fragments of rock that will not break up under rolling must be either broken up by rock hammers or explosives to the maximum specified nominal size for layered fill construction, or disposed of as unsuitable material.

Rock excavation

Rock, or rock mass includes the rock material and any discontinuities. The strength of a rock may be influenced by the type and extent of any discontinuities or defects and the degree of weathering. For more information on rock and its properties, designers, in Australia should refer to AS 1726:2017 or in New Zealand to New Zealand Geotechnical Society Inc. (2005).

Extensively fractured, jointed or discontinuous rock may be capable of being ripped and this is typically indicated on core logs and geological mapping produced from coring and seismic survey data. A measurement of the uniaxial compression strength (refer to Appendix B.6.1) alone does not necessarily indicate difficulty in ripping. However, such testing may provide an indication of whether the material excavated can be broken up by rollers or needs to be split into smaller particle sizes by rock hammers or explosives.

Geotechnical investigations

Geotechnical investigations to assess the location of rock include:

- seismic refraction surveys to measure seismic velocity to assist in the assessment of rock depth and quality for rippability purposes (refer to Appendix B.3.1)
- bore holes and test pits to assess the depth to rock and rock quality (refer to Appendix B.3.2).

Batter slopes

The excavation of a road cutting results in removal of the side support of the higher ground on one or both sides of the cutting. As a result, the sides of the cutting and areas some distance from the cutting may become unstable and prone to land slips or falling rock. The risks associated with such events are high and in extreme cases, can result in road closures, death or personal injury and extensive damage to abutting property and the road itself. The proximity, type and condition of adjacent buildings and other structures also need to be considered.

The determination of the maximum batter slopes depends on such aspects as the:

- types of materials in the cutting
- flow of ground water
- abutting vegetation
- location of buildings
- angle of rock and soil bedding planes relative to the batter slope
- presence of soft materials that are easily eroded by surface water.

For deep cuttings, it is common practice to provide 3 m to 4 m wide safety benches at regular intervals depending on the slope stability, drainage of ground water permeating through the sides of the cutting, and available width of the road reservation. Benching reduces risks associated with land slips and falling rock, facilitates the maintenance and repair of cut batters and improves the safety of maintenance workers.

Generally, for cuttings through soft, highly fractured or weathered rock and soil, the maximum batter slopes should be no steeper than 2:1 (H:V) so planting can be established on the face of the batter to prevent soil erosion and improve stability. Cuttings through stable rock formations where planting is not required to prevent soil erosion, may typically be steepened to between 1.5:1 and 1:1. Cuttings through monolithic and stable rock formations requiring excavation by use of explosives may be further steepened to minimise the amount of rock excavation and land acquisition required.

The batter slopes adopted may depend not only on the stability of the material as determined by geotechnical design, but also require consideration of a number of aspects such as aesthetics, landscaping requirements and whether or not there is a shortfall of fill. When considering any landscaping, the road agency’s requirements, particularly for the types of vegetation, need to be considered.

If the road reservation is not wide enough to provide suitable batter slopes, treatments such as soil nailing, thatching, sprayed concrete, retaining walls, reinforced earth, gabions or rock walls may be used to provide the required stability or resistance to erosion.

Suitability of materials

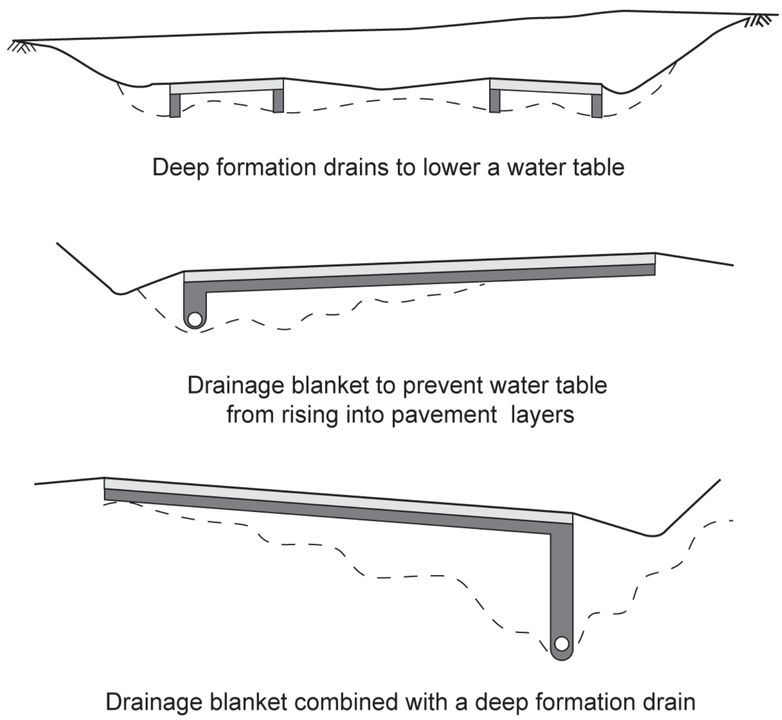
It is important that the geotechnical investigation identifies the location and extent of various materials in cuttings and borrow areas that may be suitable for use as select fill, structural fill, capping layer, and pavement subbase, particularly if imported materials are significantly more costly. Materials suitable for re-use may be stockpiled for later use on other stages of the project or on other projects. In locations where significant quantities of rock suitable for re-use can be obtained, it may be possible to set up a mobile crushing plant to produce crushed rock.

Interception of ground water

Road cuttings can attract ground water by lowering the surrounding water table or by intercepting ground water flows such as natural springs or aquifers. A requirement of the geotechnical investigation is to assess the level of the water table and predict the flow rates of ground water likely to be discharged. For further information, refer to the *Guide to Pavement Technology Part 10: Subsurface Drainage* (Austroads 2009b)

Chemical testing of ground water (see Appendix B.6.2) is undertaken to check if there is an excessive amount of dissolved salts present that would prevent it from being discharged into the surface drainage system and natural watercourses without treatment or dilution. The effect of lowering the water table beneath land adjacent to the cutting also needs to be considered. To prevent ground water entering and weakening the subgrade and pavement layers it may be necessary to design a special subsurface drainage system to intercept ground water below subgrade level (Figure B 14). Special subsurface drainage systems include deep formation drains and filter blankets (refer to the *Guide to Road Design Part 5A: Drainage: Road Surface, Networks, Basins and Subsurface* (Austroads 2013c) and Austroads (2009b)).

Figure B 14: Interception of ground water



Source: VicRoads (2004).

Geotechnical investigations required for cuttings

Geotechnical investigations that are commonly used for cuttings and borrow areas include:

- seismic refraction surveys for cuttings through rock to measure seismic velocity to assist with the assessment of rock depth and quality for rippability assessment (refer to Appendix B.3.1)
- auger holes in soft friable materials and diamond drill coring for rock to assess the soil and rock strata profile both longitudinally and transversely including the strength and quality of materials encountered (refer to Appendix B.3.2)
- trenches to obtain larger samples of materials for laboratory testing and provide a more comprehensive assessment of the materials likely to be encountered and their ease of excavation (refer to Appendix B.3.5)
- standpipe piezometers to assess ground water conditions and predicted flow rates and for sampling and testing the chemical composition of ground water (refer to Appendix B.3.4)
- penetrometer tests for shallow cuttings through soft soil to assess the resistance to penetration and to estimate the in situ CBR at various depths down to at least 1.5 m below the proposed subgrade level (refer to Appendix B.3.3).

It is important that any underground services are precisely located by a representative of the utility agency before any material is excavated.

The need for special treatments in cuttings such as retaining walls, batter stabilisation, and deep subsurface drainage systems should also be identified (see Appendix B.7 for more detail on some of the more common special treatments used in cuttings).

B.4.5 Embankments

The ground conditions where fill embankments, particularly embankment heights exceeding 5 m, are to be placed, require assessment for the likely depth of topsoil stripping, the amount and extent of over-wet or unsuitable material present, the need for special treatments over swampy ground and recommended batter slopes.

Depth of topsoil

Topsoil stripping is generally undertaken to remove any vegetable matter or seed-bearing soil prior to the earthworks phase. The depth of stripping may not always be apparent, and it may be necessary to vary the depth due to different material types. Accordingly, it may be appropriate to seek geotechnical advice regarding the depth of stripping required along the project length.

A geotechnical assessment can be made of the depth of suitable topsoil available for landscaping of batters, verges and medians. The depth of topsoil typically removed from areas on which fill is to be placed is often substantially greater in low-lying areas than on higher ground to be excavated from cuttings. This imbalance can make up for any shortfall of topsoil obtained from cuttings and needs to be accounted for in the calculation of earthworks quantities and achieving balanced earthworks.

Embankment foundations are normally assessed from test pit or borehole information taken at about 100 m to 500 m intervals along the route depending on the ground conditions.

Stability of areas for fill placement

All embankments and more particularly the material on which fill is placed will experience some settlement during and after construction. The amount of settlement largely depends on the height of the embankment, the type of materials within the embankment and how well these materials have been compacted, but more on particularly the density and moisture condition of the material on which the embankment is constructed. A geotechnical investigation can identify embankment sites that are prone to settlement during and after construction and make a prediction of the rate of consolidation and the point when further consolidation will fall within acceptable limits.

The nature of the materials and the speed of construction will also affect the time at which further settlement due to consolidation of an embankment stabilises. Most initial consolidation takes place during construction of the embankment, but for high embankments and embankments with poor foundation conditions, it may be necessary to wait until the settlement of the embankment stabilises before commencing pavement construction and structural foundations. The rate of consolidation of embankments is typically monitored at a number of strategic points by an accurate survey of levels taken over time.

As the rate of consolidation is largely dependent on the properties of the material on which the embankment is placed, the geotechnical investigation should identify materials beneath the proposed fill that may require removal and replacement with higher quality materials in order to shorten the time required for settlement to stabilise. In extreme cases (e.g. where there is a risk of shear failure of the underlying saturated soils) the geotechnical investigation should recommend whether special treatments are necessary to stabilise and/or dry out the underlying material such as the installation of:

- rock rafts and drainage blankets
- lightweight fill incorporating polystyrene blocks
- geotextiles and geogrids (i.e. a reinforcing mesh made of polypropylene) (refer to Austroads 2009e)
- dewatering systems such as well points and/or wick drains.

Slope of embankment batters

Embankment batters should be designed with a traversable slope flatter than 4:1 (H:V). Slopes steeper than 3:1 are considered hazardous and where this slope is required, some form of retaining or protection structure is likely to be required. For road safety considerations, flatter batters are required and so when determining a batter slope, guidance should also be obtained from the Guide to Road Design Part 3: Geometric Design (Austroads 2016a) and the Guide to Road Design Part 6: Roadside Design, Safety and Barriers (Austroads 2020a).

Typical structures used to retain embankments are:

- reinforced earth (pre-cast concrete panels or masonry blocks held by long steel straps between layers of fill)
- gravity gabion walls (rocks in wire baskets placed like bricks)
- crib walls (structural framework of concrete or timber interlocking segments with the spaces between the segments filled with soil)
- reinforced concrete walls
- gravity walls constructed of masonry or rocks.

Reinforced concrete retaining walls and low gravity walls can be constructed with a vertical face, but gravity walls including crib and gabion walls are typically sloped back at a slight angle depending on the type and height of the wall (refer to Appendix B.7 for more detail and illustrations of special treatments that may be required for steep fill batters).

Rock fill

Rock that is not readily broken down may be placed as rock fill up to a maximum particle size of 400 mm where a vibrating roller may be used to seat each rock particle so that sound particle-to-particle contact is achieved. Because of the higher and variable air voids in rock fill, control of density and moisture control is not as necessary as it is for relatively low strength rock.

The rock strength can be tested with the point load test (refer to Appendix B.6.1 Point Load Test) to indicate whether rock spalls are capable of being broken down during compaction. As a general guide, rock with an IS (50) point load strength index of more than 1.5 MPa may indicate that the rock is too difficult to break up under rolling. The point load strength index tends to be ‘rock type specific’ and other limits may be specified for different rock types.

Aspects that should be considered in placing rock fill are:

- large rock spalls or fragments that will not readily breakdown under rollers will either require pre-splitting to the maximum specified nominal size (typically 400 mm or less) before they are placed as common filling or alternatively, put through a crushing plant and converted to a select fill or lower subbase material
- if practical, large rock spalls or floaters need to be separated from soil and may be placed as clean rock fill or crushed to produce select filling or pavement material
  Most specifications define the maximum size rock (generally about 400 mm) that can be placed for various types of fill and a minimum depth from the subgrade level where larger sized material can be placed.
- a geotextile fabric may be specified to separate rock fill from softer friable material (blinding layers) placed between the rock fill and the subgrade
- larger rock fragments or spalls greater than 400 mm can be used as non-structural fill such as rock protection, batter flattening, noise mounds and landscaping
- large rock may impact adversely on drainage culverts.

Geotechnical investigations required for embankments

The geotechnical investigations and monitoring systems that may be required to determine fill batter slopes include:

- cone penetrometer tests to determine the depth, and penetration resistance of soft saturated soils beneath proposed embankments (refer to Appendix B.3.3)
- removal of undisturbed samples for consolidation and shear testing (refer to Appendix B.6)
- information to allow the minimum batter slopes to be determined for embankments, having regard to the properties of the soil proposed for embankment construction including resistance to soil erosion
- monitoring of horizontal and/or vertical movement during and after placement of the embankment.

B.4.6 Pavements

General

In order to develop a road design it is necessary to have completed the design of the pavements. Large projects often require several pavement designs for different lengths or elements of the project where there are different traffic loadings or subgrade strengths. For example, a different pavement composition may be adopted in rock cuttings than in fill areas constructed on low strength or expansive soils. Freeway ramps, overpass embankments and frontage roads may also have a different structural thickness and composition to that used for the main carriageways.

In situ materials found along the alignment will normally be tested to assess whether they are suitable for use as selected fill, capping layer, pavement subbase or base. Materials obtained from the site generally result in considerable savings compared to materials imported from external commercial sources such as a quarry that may be a considerable distance away from the site. A detailed laboratory evaluation of in situ materials is essential to enable decisions to be made on how these materials are best used.

For pavement design purposes, an assessment is made of the CBR and percentage swell of in situ materials used at or near subgrade level, including the material to be used for select fill or capping layers, or for the pavement itself, where naturally occurring materials are being considered. The pavement designer uses this information together with the traffic loadings to determine the structural thickness of the pavement layers. Generally, it is sound economic practice to provide a good quality capping or select fill layer with a CBR higher than the in situ or common fill, as this can reduce the overall pavement thickness (for guidance on pavement design refer to Austroads (2017d)). Supply of additional pavement material is significantly more expensive than fill materials obtained from the site.

For pavements constructed over highly expansive materials a minimum cover of 0.6 m to 1.0 m from the finished pavement surface level to the top of the expansive material may be specified. Strategies that may be adopted in these situations are outlined in Austroads (2017d).

Rehabilitation and strengthening of existing pavements

Pavement investigation for a greenfields site is generally restricted to investigation of potential excavated materials from cuttings for use as capping layer material, selected fill, structural fill, pavement subbase and base as described in the preceding sections.

However, many road projects require upgrading of existing pavements by widening and strengthening. In these cases, a pavement investigation is required to assess the CBR of the existing subgrade and pavement composition. Strength testing, through measuring pavement deflections, may also be undertaken. The overall objective of the investigation is to determine the suitability of the existing pavement to form part of the new pavement structure.

The depth of widening and overlay or resheet, will be a factor in determining the new finished level of the upgraded pavement. In built-up areas, due to level constraints, the only pavement rehabilitation option may be reconstruction. The existing pavement materials may however be salvaged for reuse subject to testing and evaluation.

Deflection testing is usually undertaken to determine the structural adequacy of the existing pavement. A significant advantage of the testing is that it measures in situ strength and does not rely on assumptions to be made regarding the strength of the subgrade or materials within the existing pavement. This information, in combination with pavement composition and subgrade data, is used to design an appropriate structural treatment e.g. asphalt overlay, granular resheet, stabilisation, or patching.

More information on pavement investigations and resheeting of pavements can be obtained from Austroads (2009d and 2017d) and AS 1726:2017.

Pavement design

Pavement design is typically undertaken by a specialist with the appropriate knowledge and skills. It is not uncommon practice to provide a number of optional pavement designs varying from unbound pavements with a sprayed seal or thin asphalt surfacing, thick asphalt overlying cement treated subbase or full depth asphalt pavement or various plain or reinforced rigid (concrete) options. Generally, heavily-trafficked urban roads require fully bound low maintenance pavements that resist higher traffic stresses, whereas for rural roads unbound pavements with sprayed seal, or thin asphalt surfacing are more commonly selected because of their lower cost, and relative ease of routine and periodic maintenance.

The selection of the most appropriate type of pavement will be influenced by the required design life, maintenance requirements, risk of poor performance and whole-of-life costs.

For further information, refer to Austroads (2017d).

Geotechnical investigations associated with the design of pavements

Geotechnical investigations that are typically required for pavements include:

- cone penetrometer tests to assess in situ subgrade strength and the variation in subgrade strength along the alignment, particularly beneath existing pavements
- sampling and laboratory testing of materials in cuttings and borrow areas for CBR and percentage swell and various physical properties such as grading and plasticity index
- test pits dug within existing pavements that are to be strengthened and rehabilitated progressively to determine the thickness of each pavement layer and obtain samples of each pavement material for laboratory testing
  For more information on evaluation of pavements refer to Austroads (2019a).
- coring of asphalt, cemented materials or other bound materials to quickly determine the thickness of existing pavement layers at locations where test pits for sampling of materials for laboratory testing are not required.

B.4.7 Subsurface Drainage Systems

The purpose of subsurface drainage systems is to prevent ground water from entering and softening or saturating the subgrade or pavement materials, and removing trapped water that enters a pavement, either from the side or from beneath the pavement.

Subsurface drainage systems for interception of ground water

Subsurface drainage systems for cuttings are described in Appendix B.4.4. The geotechnical investigation should establish the fluctuations in the water table, the presence of underground springs and permeable aquifers, and predict ground water flows that will occur when cuttings and fill embankments have been constructed. Large cuttings and embankments can cause a significant change in the flow of ground water. A geotechnical design may be required to determine suitable deep subsurface drains and filter blankets that will intercept the flow of ground water and distribute it into the surface drainage system.

Pavement drains

The location and configuration of subsurface drainage systems are covered in Austroads (2009b, 2013c).

Pavement drains are relatively shallow, varying from 300 mm to 400 mm below subgrade level. All pavement drains should start and finish at a drainage pit or end wall. The total continuous length of subsurface drainage pipe without a junction pit or inspection opening should not exceed 100 m to 150 m (depending on gradient) to enable periodic flushing out of fine material that may otherwise build up and cause a blockage.

Pavement drains should be provided where:

- there is a boxed formation with impermeable verges or unsealed shoulders to contain the pavement (a sub-surface drain should always be installed on the low side of the boxed pavement in fill areas and on both sides of the boxing in cuttings)
- pavement widening is to be undertaken as water may become trapped against a material of lesser permeability on the low side of the existing pavement (e.g. asphalt widening of an unbound granular pavement)
- the in situ material and fill material may have different permeability at cut to fill points.

Pavement drains should have a:

- filter material capable of efficiently transferring water to the drain pipe but which can also filter out fine grained mobile soil or silt material to prevent it entering and blocking drain pipes
- filter sock wrapped around a perforated drain pipe in locations where fine sand filter material is used in order to prevent the filter material from entering the slots in the pipe.

Geotechnical advice should be sought on the type of pavement drain and filter material to be used in relation to the grain size of the adjacent soil and whether or not a two zone filter is required. The selection of subsurface drainage arrangements will be site specific, but typical indicative treatments are as follows:

- In clayey materials where there are typically low flows of subsurface water, a perforated pipe with a filter sock is commonly used with a fine sand filter material.
- In silty material where higher flows of ground water can cause the silt particles to become mobile, a geotextile fabric is placed against the sides of the trench or a second zone of finer filter material is used in conjunction with a very permeable coarse aggregate filter material designed to intercept water and efficiently carry it to the perforated drainage pipe.
- For permeable sand and gravel materials where there may be significant flows of subsurface water, a perforated or slotted pipe with a single stage filter of very permeable coarse sand or fine aggregate that is more permeable than the subgrade material may be applied.
- Where rock material in cuttings is substantially free of soil particles, a perforated pipe with a very permeable coarse aggregate filter material may be used to cut off the possible flow of ground water and efficiently deliver it to the pipe.
- For subsurface drains located directly under or within an existing pavement (particularly in the longitudinal direction), a perforated pipe wrapped in a filter sock and backfilled with fine sand and with the remainder of the trench backfilled with a permeable no-fines concrete filter material may be suitable.

B.4.8 Footings for Structures

General

Bridge foundation investigations are normally carried out in accordance with AS(NZS) 5100:2017 *Bridge Design*.

Investigations for bridges and other types of structures such as retaining walls, reinforced earth embankments, major culverts and sign gantries are generally more concentrated with closer spacing of bore holes and penetrometer test sites. The footing conditions may affect the type of structure selected and the number of spans in the case of a bridge.

The geotechnical information must be sufficiently comprehensive to enable the structural engineer to determine the:

- type of footing required varying from friction piles, end bearing piles, bored or socketed piles, caissons or spread footings
- length, number, type, angle and arrangement of piles required for a piled footing
- depth, thickness and area of any spread footings
- thickness of base slabs for large inverted box culverts
- number, length and type of anchor straps required to retain concrete face panels for reinforced earth structures.

Geotechnical investigations required for structural footings

An accurate soil and rock profile is required at proposed sites for structures. It is important that the investigation is sufficiently comprehensive to ascertain whether or not there is rock overlying relatively lower strength rock or clay similar to the case of basalt floaters.

- Investigations include:
- CPT (cone penetrometer testing) for soils and sands to provide the depth, strength and frictional resistance of soil strata particularly where piled footings are likely
- vane shear testing of soft clay materials
- coring through stiffer soils and rock to obtain its depth, consistency and strength
- using augurs in stiffer soils and undertake standard penetration tests to obtain samples for logging and assessment of consistency
- sampling of surface and ground water for dissolved salts or other corrosive chemicals where special protective treatments may be required for steel and reinforced concrete structures particularly steel structures and corrugated steel pipes.

B.4.9 Observational Method

An approach to design and construction of structures including roads, has been developed that uses an iterative feedback loop when actual site conditions are encountered, known as the observational method. The method relies on a selected starting point for initial design, which is then amended and adjusted as the nature of the ground conditions emerge during the project. It is essentially a design method that enables designers to deal with uncertainty and risk.

In summary the method relies on a number of essential steps:

- Undertake site investigations into the general properties of the geotechnical setting of the project, and establish a geotechnical model. Review and assess likely variability of material properties.
- Undertake initial design based on a selected level of risk.
- Identify key properties to be observed during the project and evaluate sensitivity to the design of possible material property variability. Undertake a worst-case scenario analysis.
- Develop an action plan that identifies strategies to deal with material variability if encountered.
- Undertake field observations, including instrumentation and laboratory testing as appropriate, during the works to monitor and assess conditions.
- Modify the design to suit actual conditions encountered in accordance with the action plan.

Examples of where the observational method can be applied in road construction projects may include:

- Embankment construction over soft compressible soils. Monitoring of settlements can be undertaken to determine the duration of surcharging and/or preloading, and finalise finished pavement levels.
- Material sourcing from cut. When materials are exposed and removed, they may be evaluated with further assessment and testing to assess suitability for use as pavement layers or fill layers.
- Road cut batter slope support. As materials are exposed, benching and slope angles, together with slope stabilisations measures such as soil nails, drainage and netting are finalised.
- Tunnel support measures. As the tunnelling works proceed, mapping, assessment and refinement of modelling will require adjustment and changes to support measures such as rock bolting, shotcreting and drainage.

More information on the method can be found in Nicholson, Tse and Penny (1999).

B.5 Sustainable Design Practices

B.5.1 General

Road agencies play a central role in the delivery of sustainable outcomes for transport development, with key responsibilities associated with managing substantial lengths of road network, provision of services to promote diversification of transport options and facilitation of community engagement in transport planning.

Sustainable design practices are those leading to road designs that reflect not only the economic and safety aspects of the solution, but also the associated social and environmental improvement. Every opportunity should be taken to enhance social and environmental amenity, particularly if these enhancements come with only a marginal increase in the cost of the project. The focus should not be restricted to compliance with existing guidelines or simply to mitigate the adverse effects of roadwork, but to seek positive ways to enhance the overall outcome in a social and environmental sense.

This section provides some information on the importance of materials stewardship; minimisation of erosion; water-use, preservation of topsoil; and the potential use of non-standard or recycled materials. Further information on the local sustainable design policies and practices of the road agency should be obtained prior to commencing any investigation.

B.5.2 Materials Stewardship

One of the major environmental impacts of road construction activity is the clearing of native vegetation. Sometimes it is necessary to clear additional native vegetation to gain access to road building materials. In order to minimise the amount of clearing and to reduce other environmental impacts, sourcing of local materials should be considered in the light of other alternatives. This approach is termed materials stewardship and should lead to a more sustainable management of existing and future deposits of road making materials.

There are a number of ways in which extraction of materials can be undertaken to reduce the impact on local vegetation and habitat. When selecting a suitable location for extraction of road making materials consideration should be given to:

- locating gravel pits in cleared areas in preference to areas of native vegetation
- avoiding stands of significant native vegetation particularly old growth native trees
- locating gravel pits outside the road reserve on adjacent cleared land in cases where the road reserve contains the last remnants of native vegetation prior to adjacent land being cleared for agriculture or other development
- avoiding land that is reserved or likely to be reserved for future conservation
- minimising the area required for clearing by avoiding shallow gravel deposits in preference to deeper deposits to give a higher yield per hectare of affected land
- selection of gravel deposits with a maximum level at least 0.5 m above the water table
- location of gravel pits on land with a low-environmental significance in preference to undisturbed ecosystems.

Regardless of tenure, areas of cleared land should always be investigated as a source of suitable material prior to considering areas covered with native vegetation.

B.5.3 Minimisation of Erosion

In order to minimise the potential for erosion and land slips, the road alignment should be selected to avoid unstable soils, steep topography, and proximity to parallel streams.

The geotechnical investigation should clearly identify the location of all soil types particularly dispersive and erodible soils where special treatments may be required to mitigate soil erosion. The maximum sustainable velocity for overland water flow and in open drains should be determined for various materials. Consideration should also be given to the erosive power of stormwater flowing from a culvert outlet so the designer can ensure that the design outflow velocity considers the local soils and minimises the potential for downstream scouring. If the soils are dispersive then very detailed treatments will most likely be required.

The designer should use strategies that minimise the volume of water and sediment flowing off the road pavements and formation. The designer should therefore consider:

- using retarding basins, silt traps and debris racks to minimise deposits of eroded material and debris that may interfere with the natural flow of water in streams
- limiting the cut and fill batters in relatively low-strength rock and soil materials to a maximum of 2:1 (H:V) to enable vegetation to be readily re-established
- using special batter lining systems for relatively low-strength rock and soil with batters steeper than 2:1
- thatching or lining of open drains through soils or sands where scour is likely to occur, and installation of rock weirs or drop structures to slow water velocity as necessary
- locating any appurtenances such as open drains clear of significant stands of trees to minimise clearing

- where there is sufficient road reserve space, designing batters to be 6:1 or flatter to support denser plant growth and further reduce the potential for soil erosion (notwithstanding that use of flat fill batters may avoid the use of safety barriers). However, incorporation of very flat batters may not be the best solution from a soil erosion perspective if it substantially increases the amount of heavy clearing required.

Further information on soil erosion can be found in Appendix B.5.3 and the *Guide to Road Design Part 5: Drainage: General and Hydrology Considerations* (Austroads 2013b).

B.5.4 Water for Construction and Landscaping Purposes

Use of water is an increasing concern and it is becoming clear that serious measures are required to conserve water for domestic and industrial use. Use of town water or water extracted from local streams for road construction is being perceived by some sections of the community as being water wasteful. Therefore, alternative water sources such as recycled or bore water should be used.

The geotechnical investigation should identify sources of water for construction, including whether or not underground water can be obtained from bores or natural springs, and whether temporary dams or permanent water features could be established as part of the landscaping.

Landscaping should comprise indigenous species of plants that require less water to establish. In areas where there is a likelihood of water shortage for construction purposes and to establish vegetation, consideration should be given to the inclusion of special features in the design such as:

- the creation of ornamental dams or lakes within the road reserve as a feature of the roadside landscaping in locations where the road reserve is wider than required for the road formation
- temporary dams in abutting property that would not contravene regulations by the local water management authority
- a means of capturing water from underground springs likely to be intercepted by earthworks and drainage, for use as construction watering and for establishing and maintaining new vegetation planted as part of the project landscaping
- specifying measures for the effective use of water generally, and specifically to promote the survival of plants and trees (e.g. early mulching of landscaped areas to retain moisture content in soils).

Some road agencies use non-potable water for all construction and maintenance where feasible, and so the local policies and practices on the use of water should also be obtained.

B.5.5 Preservation of Topsoil

The geotechnical investigation should clearly identify the depth of available topsoil in both cut and fill areas. This information can be used by the designer to calculate the depth of stripping required not only to prevent organic material from being mixed with or covered by common fill but to source additional topsoil. Increasing the depth of topsoil excavation beneath fill areas (if available) can make up for potential shortfalls in other areas such as medians, verges and batters. Topsoil is also required to restore borrow pits after completion of materials extraction.

It is important and cost-effective that all stripped topsoil should be used within close proximity to its source. The topsoil which is generally stripped as part of the site clearing activity contains local seed and some composted material that will assist with the regeneration of local vegetation. Local topsoil is an important commodity required to sustain and retain grasses and plants to a particular location along the project. Bringing topsoil from remote locations should be avoided if possible as it may result in the importation of undesirable weeds and plants or disease. Maintaining grass and plant species native to the area is not only environmentally sound, it also minimises the spread of noxious weeds, and seeds and plants are likely to be more tolerant of the long term local weather conditions. Imported topsoil should be certified as being free of pathogens, toxic levels of any element and any weeds or their roots.

B.5.6 Use of Non-standard or Recycled Materials

Rural roads have traditionally been paved with naturally occurring materials where there are workable quantities within an economic haul distance from the project site. However, such materials are becoming scarce. More use is being made of quarried or manufactured materials that are generally more costly than natural materials. Nevertheless, consideration should always be given to the use of locally available material that may be non-standard but have been proven to function well under local conditions particularly in arid areas.

Local knowledge and experience in using non-standard materials may encourage the pavement designer to consider modifying the pavement composition to incorporate these types of materials. When considering using the non-standard materials, the pavement designer should seek any local knowledge from road agency staff and a geotechnical expert to devise a suitable testing regime, or quality control system. A field trial of the material could be considered to confirm the likelihood of success, and the cost relative to the provision of a more conventional material.

Many naturally occurring but substandard pavement materials can be blended with a crushed product prior to stabilisation with an appropriate binder, e.g. bitumen or cement, to form a material that performs satisfactorily. In some cases blending two materials together (granular stabilisation) can produce a resultant material of sufficient quality in terms of grading and plasticity without the need to add a binder. This form of granular or mechanical stabilisation is discussed in greater detail in Austroads (2009c, 2019f).

Most road agencies promote the use of recycled materials in pavements provided that the materials can be used in such a way as to achieve satisfactory field performance. Some of the recycled materials commonly used in road pavements include:

- pulverised existing pavement material and bituminous surfacing, stabilised in situ with an appropriate binder to produce a stronger and less moisture sensitive material for use as pavement material
- recycled crushed concrete produced to a similar specification as crushed rock but with maximum limits on the mass of foreign materials such as crushed brick, glass, wood and other foreign organic materials
- blast furnace slag ground into a powder to become a major portion of slow and medium setting cementitious binders
- blast furnace slag crushed to a specified grading for use as a cementitious pavement subbase
- crumbed rubber added to bitumen to produce a strain alleviating membrane (SAM) seal surfacing
- milled or crushed recycled asphalt added to a new asphalt mixture.

The geotechnical investigation should also identify local natural pavement materials that can be stabilised in situ to produce a satisfactory material.

Further information is also available in the *Guide to Pavement Technology Part 4E: Recycled Materials* (Austroads 2009c).

B.6 Laboratory Tests

B.6.1 Tests Related to Engineering Properties

General

Testing the engineering properties of rock requires a clear distinction between tests that relate to the discontinuities within the rock and those that are relevant to the solid rock mass. The presence of moisture can also affect the behaviour of discontinuous or fractured rock.

Testing for the engineering properties of soils requires the specification of test conditions such as density, moisture content, drained or undrained state specimens and pre- or post-consolidated state, in an attempt to replicate as far as is possible, the likely field conditions or worst case scenario.

Austroads (2009a, 2017d) also provide information on materials testing and so only the following examples of the more common laboratory tests on soil and rock required for design purposes have been summarised.

Unconfined Compression Strength Test

The unconfined compression strength is the maximum vertical stress an unconfined cylindrical specimen of rock or highly bound material can withstand before crushing or collapsing. This is a simple test to assess the bearing or shear strength of rock for design of structural elements such as end bearing piles or spread footings, and for assessment of the stability of rock cut batters where discontinuities, fractures, and soft bedding planes are evident.

The specimen, typically with a height to diameter ratio of 2:1 must be capable of standing unsupported in the test machine.

Triaxial Compression Test

The triaxial test is used to measure the likely shear strength of a cylindrical moulded specimen of soil or fractured rock (typically with a height to diameter ratio of 2:1). The specimen is placed in a waterproof membrane and subjected to various combinations of vertical stress and horizontal confining pressure in the device (via water pressure surrounding the membrane) to assess the shear strength likely to be achieved at various distances from the surface or load source. The shear strength of a soil is very much related to the degree of confinement it receives from the surrounding soil and the triaxial test attempts to replicate stress conditions at various depths.

Usually the test specimen is tested in a drained condition (no pore pressure) or sometimes in an undrained condition where pore pressure is allowed to develop and can be measured. The test is useful to assess the bearing pressure for the design of foundations, soil stability and for estimating the rate of consolidation. The triaxial test can test samples under varying degrees of consolidation (density) and moisture content, and usually requires the advice of an experienced geotechnical engineer to specify the test conditions.

Direct Shear Test

This test utilises the direct shear box and is used to derive the shear strength of a soil or failure plane. It is commonly used for coarse grained materials such as sand or gravel with low cohesion because specimen preparation is easier than for the triaxial compression test. The test is used for similar purposes as the triaxial compression test but is more versatile for most types of unbound or lightly bound materials where the drainage condition can be controlled.

The apparatus automatically applies both horizontal and vertical loads to a test specimen that is confined within the shear box. Readings are taken until the horizontal shear load peaks and then falls, or the horizontal displacement reaches 15% of the diameter of the shear box. The shear stress can then be plotted against the displacement and a maximum shear stress determined for the sample.

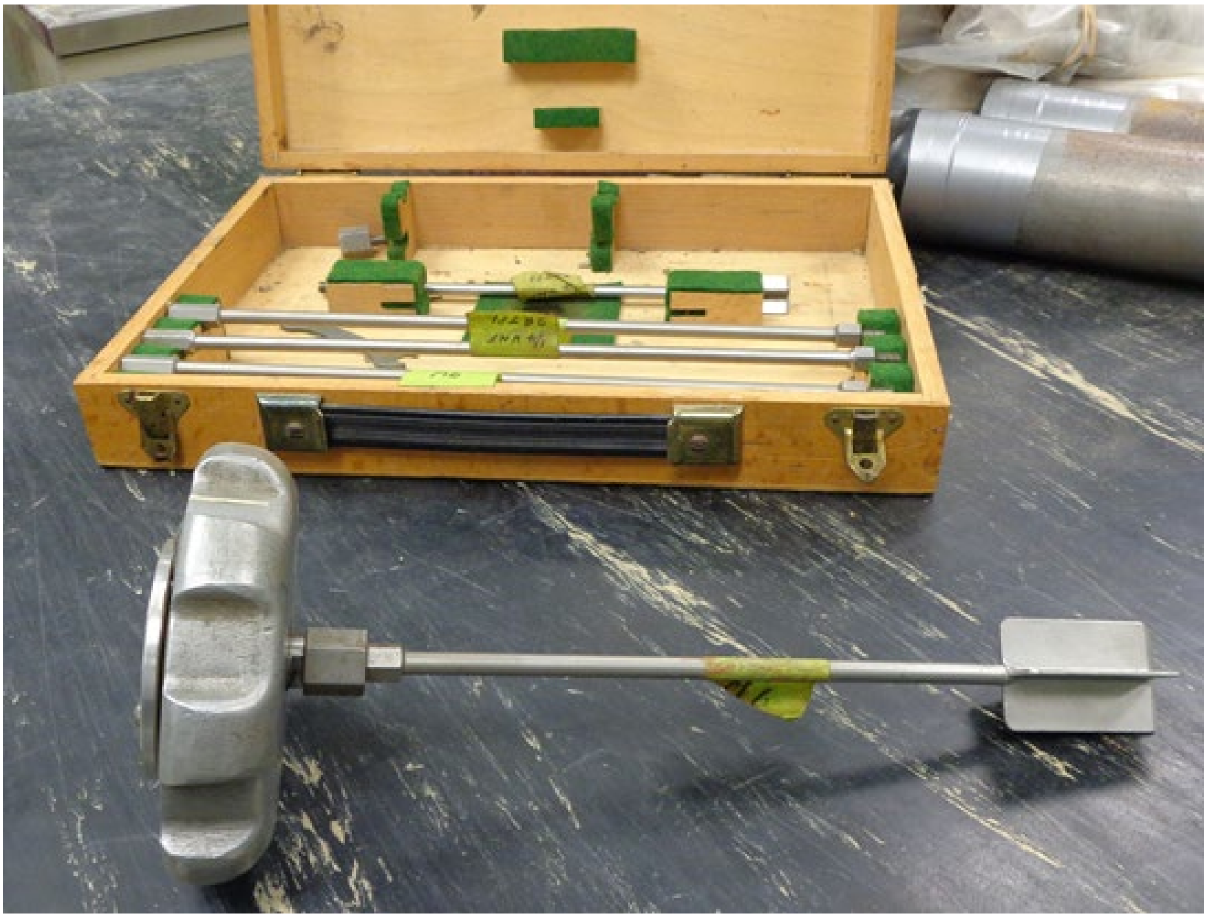
Vane Shear Test

This is a simple in situ torsional shear test to assess the shear strength of soils and is typically applied to a soft clayey material. The test is commonly used in the field but can be applied to a moulded laboratory sample. The test requires the insertion of a vane into soft clay, usually into the bottom of a 100 mm bore hole. A torsion wrench or some other mechanical means is used to rotate the vane at a rate of 6° to 12° per minute until the soil yields. The peak torque is measured.

The shear stress is determined from the area of the vane and force applied. The advantage of the test is that it can be applied in situ to cohesive clay materials in the natural state of density and moisture content. A laboratory vane shear test can be undertaken on an undisturbed sample of clay from the site or a laboratory prepared sample to a pre-determined density.

The test can be undertaken using a portable kit as shown in Figure B 15.

Figure B 15: Portable vane shear test kit

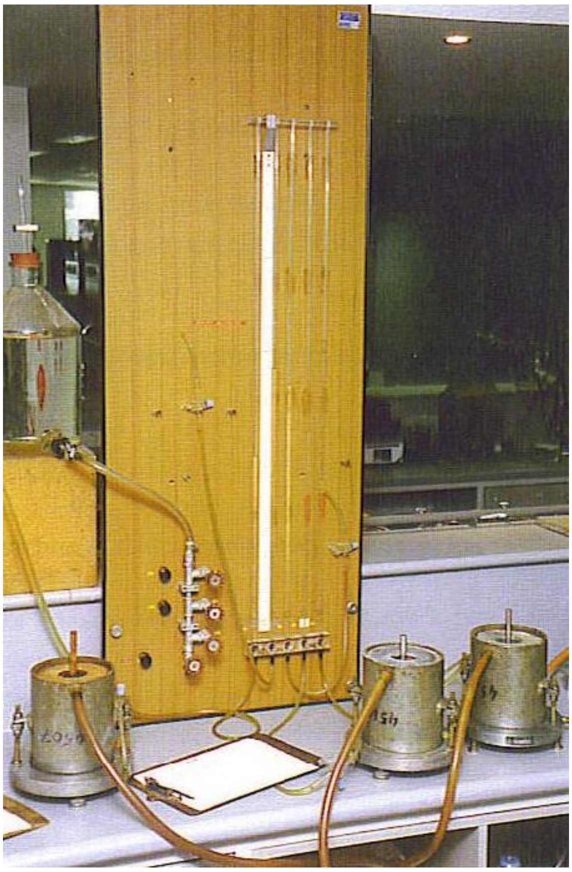


Permeability Test

The permeability test is used to measure the flow rate of water in m/s through a 150 mm by 100 mm sample of material compacted in a CBR mould under specified test conditions (Figure B 16). The test may be conducted with a constant or variable head of water.

Specifications may require a minimum permeability for filter materials used for drainage blankets and subsurface drains. For a pavement subbase material a minimum permeability may be specified to require that the permeability of the pavement increases with depth and that water can drain through the pavement to the sub-surface drainage system. A maximum permeability may be specified for verge fill and crushed rock base material to minimise entry of water to the pavement. In the case of a capping layer a maximum permeability is generally specified to minimise moisture movement and hence the volume change of an underlying expansive material such as basaltic clay.

Figure B 16: Constant head permeameter



Source: VicRoads (2007).

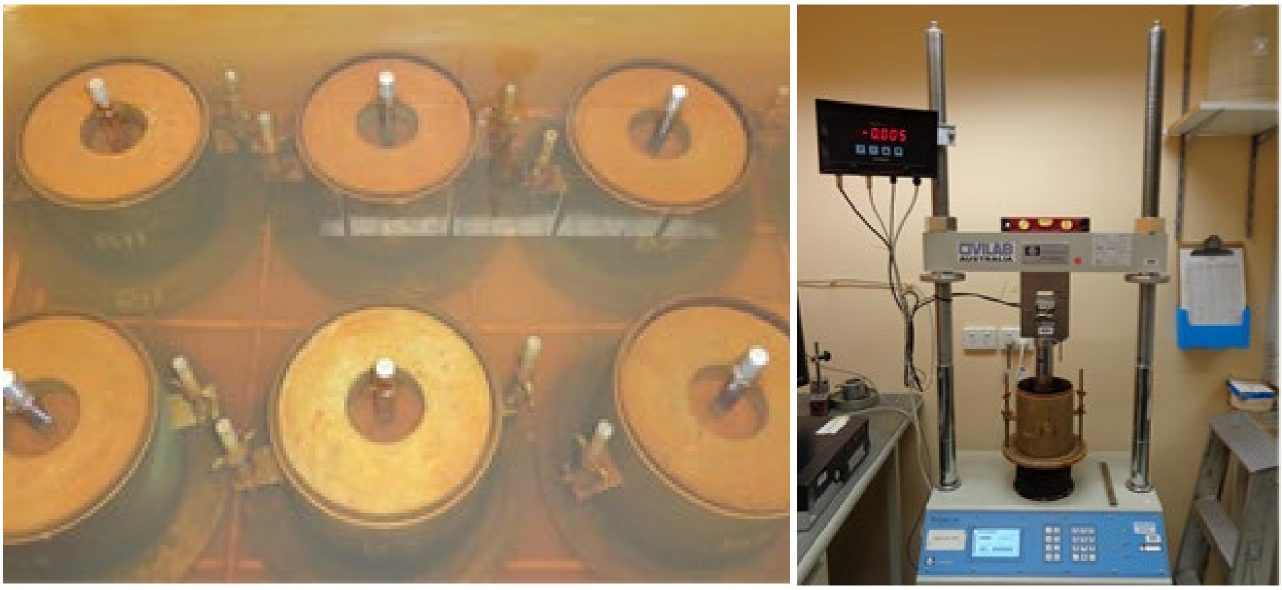
California Bearing Ratio (CBR) and Percentage Swell

CBR test

One of the most common empirical tests used to characterise the strength of subgrade and pavement materials is the CBR. It is both an indirect indicator of shear strength and, to a lesser extent, the bearing strength.

A soil specimen is compacted to a specified density at or near optimum moisture content (OMC) in a 150 mm diameter mould to a depth of approximately 100 mm. The CBR is commonly used to provide a strength characterisation of a material in a saturated (or weakest) state so the test specimen is pre-conditioned by soaking it in a water bath for an appropriate period as shown in Figure B 17(a) (typically for four days but can be as high as 10 days for materials with very low permeability).

Figure B 17: Components of the CBR test



Soaking *Test rig*

Surcharge weights and sample after testing

The CBR test requires the test specimen to be loaded with a 50 mm diameter plunger at a specified rate of penetration into the specimen (refer to Figure B 17(b)). The maximum force required to penetrate the specimen for a depth of 20 mm is measured and recorded. A formula is used to calculate the CBR which is recorded as a percentage.

In arid areas the CBR may be measured at the highest in situ moisture content likely to be experienced rather than in a saturated condition. Alternatively, some jurisdictions may determine an appropriate CBR for arid areas by applying a factor to the soaked CBR value for a material. This factor is based on the ratio of average annual rainfall to the average annual evaporation rate obtained from the Bureau of Meteorology.

The CBR has become a universal soil test that is used to characterise subgrade materials on which pavement thickness design charts are based. It is also used to characterise pavement subbase materials with CBR values generally less than 100%. The test is not considered sufficiently reliable for characterising pavement base materials with CBR values exceeding 100%. The test method also allows a surcharge annulus shown in Figure B 17(c) to be placed on top of the sample to simulate the weight and vertical confinement provided by overlying pavement layers. The use of the surcharge (standardised at 4.5 kg by some road agencies) increases the CBR value obtained for a given material.

Percentage swell

The percentage swell is a measure of the change in volume of a CBR specimen confined in the mould during a four day soaking period and is an indication of the swell potential of the material. The percentage swell is the ratio of the gain in vertical height resulting from soaking to the original specimen height prior to soaking, expressed as a percentage. Highly expansive materials are regarded as materials with a percentage swell > 2.5%. This test is shown in Figure B 18.

Figure B 18: Percentage swell test

Figure B 19: Point load test

Point Load Test

This is a simple test to characterise the strength of rock and can either be performed as a field test or laboratory test for a rapid assessment. The point load test can be used to discriminate between rock that cannot be broken down under rolling, and relatively low strength rock that will break down into a soil-like material. Rock may be used as clean rock fill after breaking down with explosives or rock hammers. Where rock spalls are vibrated into place to achieve rock to rock contact, moisture content and density limits do not apply. Relatively low strength rock that can be readily broken down under rolling may produce a soil-like material that can be subjected to the usual specified density and moisture control requirements.

The test requires a specimen of rock (usually a cylindrical core for best results) to be mounted between two conical steel platens with a load applied to the lower platen by use of a hydraulic jack (Figure B 19). The maximum force applied to the upper platen is recorded as the point load index. This force is normalised to an equivalent load required to fracture a 50 mm diameter core called the $I_{S\,(50)}$ value. Relationships, depending on rock type, have been derived to convert the $I_{S\,(50)}$ value to an estimated compressive strength. The test can be used for rectangular or irregular shaped pieces of rock provided that a correction factor is applied. However, such specimens provide a less accurate assessment than a test undertaken on a regular cylindrical specimen.

B.6.2 Physical or Empirical Properties

Austroads (2009a) also provide information on materials properties and so only the four descriptions have been summarised below.

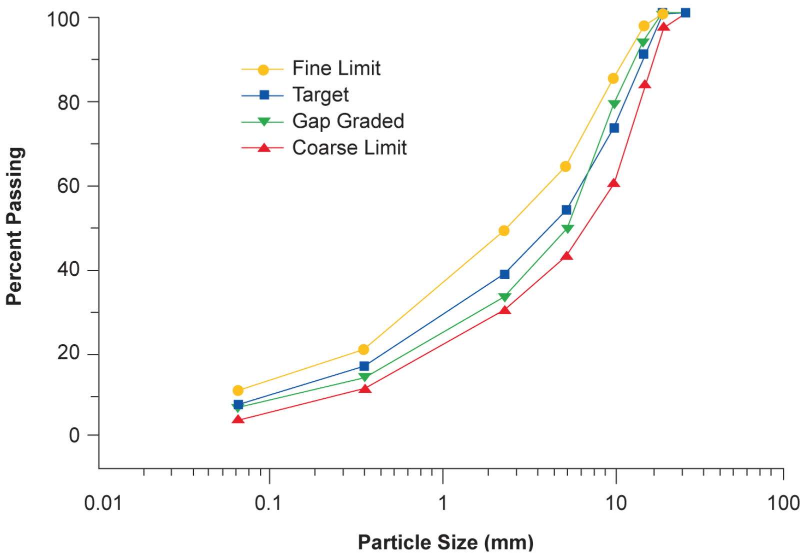
Particle Size Distribution (Grading)

The particle size distribution represents the mass of dry material retained on each sieve of a nest of Australian Standard sieves (Figure B 20) ranging from the maximum permitted size for the material down to that passing a 0.075 mm sieve size, expressed as a percentage of the total mass of material used in the test. The results are typically given in a tabular form but can be plotted in a graphical format with the sieve size shown on a logarithmic scale to improve the shape of the grading curve (Figure B 21).

A well graded material is one where the smaller particles fill most of the air voids between the larger sized particles once the material is fully compacted. Poorly graded materials typically have a lower strength and may be highly permeable if there are insufficient fine particles present to fill the air voids. For common fill and structural pavement layers a dense graded material is usually specified. Filter blankets and subsurface drains require permeable filter material that is regarded as open graded materials with a low percentage of fines. A minimum permeability requirement may be specified.

Figure B 20: Mechanical sieve shaker

Figure B 21: Example of a grading or particle size distribution



Source: VicRoads.

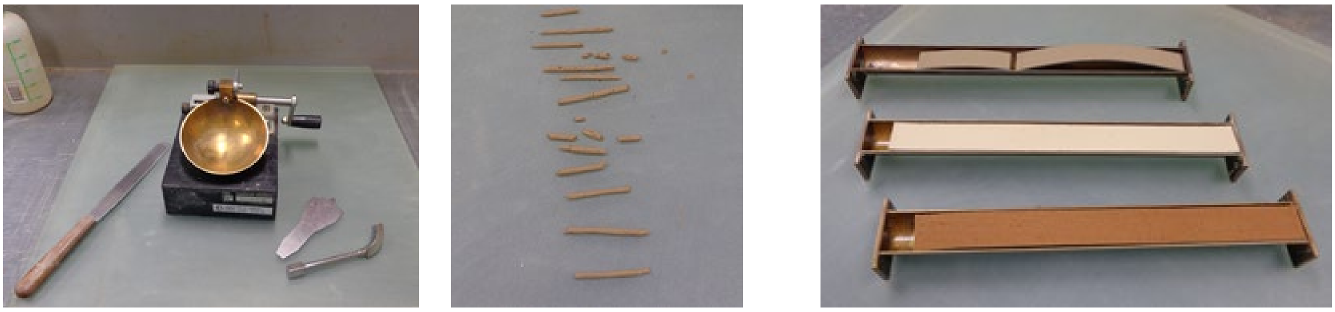
Atterberg Tests (Liquid Limit and Plastic Limit)

These tests are shown in Figure B 22. As water is added to the fine fraction of a material, the internal cohesion reduces and eventually the mixture becomes a liquid with the material particles in suspension with no effective particle interlock. The moisture content at which this occurs is known as the liquid limit. If the material is allowed to slowly dry out it goes through a plastic stage where it can be moulded into a shape. The moisture content where the material becomes too dry to mould into shape or be rolled into narrow threads is known as the plastic limit.

The plasticity index (PI) is the numerical difference between the liquid limit and plastic limit of a soil. The PI is an indicator of the amount of clayey minerals and fines in the portion of the material passing the 0.425 mm sieve. Generally, materials with a PI > 10 are regarded as cohesive materials but may be prone to shrinkage cracking and permanent deformation under load. For a pavement base material it is desirable that the material has some cohesion. For this reason a lower limit for PI for a pavement base material of about 2 in addition to an upper limit of about 6 is typically specified. A material with a PI of 0 is regarded as non-cohesive and more permeable than desirable. Such a material can be difficult to handle, and it may not be possible to achieve the desired compaction.

The linear shrinkage of a material is the percent of volume loss after oven drying of the fine fraction of a material that has been made into a paste at or near the liquid limit. For a given material, the linear shrinkage is related to the PI and can be compared with the PI test results to cross check for outlier PI results.

Figure B 22: Atterberg test



Liquid limit test *Plastic limit test* *Linear shrinkage test mould*

Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)

For materials within a road formation that require compaction to a specified characteristic or mean density ratio (ratio of the dry density achieved after field compaction to the MDD achieved in the laboratory), it is necessary to determine the MDD and OMC for various types of soil and relatively low strength rock materials encountered in an investigation. Test samples for the CBR test are typically compacted to between 95% and 98% of MDD to simulate the average density achieved after field compaction. Two standards of compaction for the moulded sample are available:

- standard compaction effort for earthworks materials using the standard (or smaller) laboratory impact hammer with a lower height of drop
- modified compaction effort for pavement materials using the heavier impact hammer with a higher drop to impart more compaction energy to the specimen.

The devices used for compaction are shown in Figure B 23.

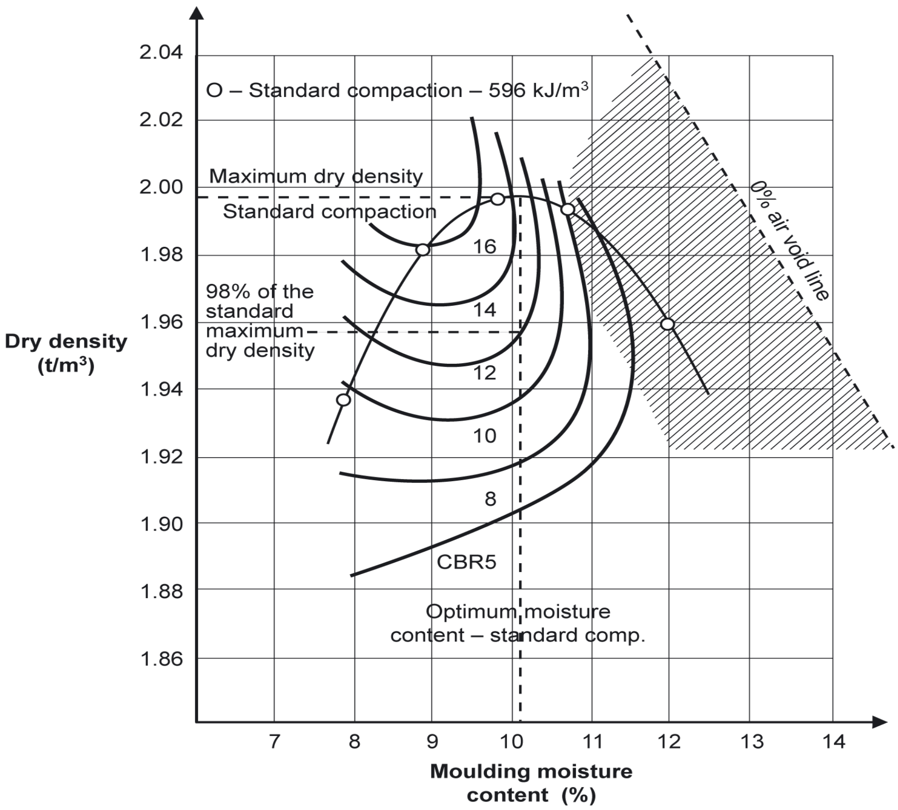
Some road agencies use standard compaction effort for all materials but specify a higher density ratio to be achieved for pavement materials (generally over 100%).

Figure B 23: Modified (left) and standard (right) compaction hammers

Source: VicRoads (n.d.).

The OMC and MDD are determined from a curve produced from a plot of the dry density versus moisture content of oven-dried soil samples after compaction. At least four different moisture contents are required to be plotted both above and below the estimated OMC. Once the mass of dry soil and mass of water (moisture content) for each of the compacted specimens is known, the moisture ratio of each specimen can be determined. The MDD is the density at the highest point (peak density) on the density versus moisture content curve and the OMC is the moisture content where the peak density (MDD) has occurred as determined on the moisture content axis. A typical graph is shown in Figure B 24.

Figure B 24: Relationship between dry density and moisture content



Chemical Testing of Water and Soils

Chemical analysis of soils and water (such as pH and conductivity) is undertaken to assess the presence of dissolved salts, acid sulphates or other undesirable contaminants. Water containing chemicals can leach out of cuttings, stockpiles of excavated fill material or fill embankments and potentially cause harm to the environment (e.g. by killing nearby vegetation). In these cases special provisions are made to contain, treat or dilute discharged water with higher than permitted dissolved salts. Soils that contain acid sulphates can produce a leachate that is harmful to plant life. Such materials must be disposed of to a suitable containment site or in some cases encapsulated deep inside a large embankment.

Water quality testing can be important when corrugated steel pipes are being considered or where salt water is likely to be encountered. For the former, a conductivity test can be undertaken that will assist in determining the propensity for accelerated corrosion of the steel, and for the latter, testing will allow an analysis of the risk to reinforcing steel in concrete pipes.

Generally, water that contains more than 3000 mg/L of dissolved salts and has a conductivity > 3500 μS/cm (microsiemens/cm) is not suitable for watering a pavement base course as excessive salt formed on drying may cause the bituminous surfacing to bubble up and lift off the surface.

B.7 Special Geotechnical Design Systems

B.7.1 General

Special geotechnical treatments may be required for abnormally difficult circumstances. Solutions may be quite complex and site specific and these matters should always be referred to a suitably qualified and experienced geotechnical engineer for advice. Special treatments will typically require project specific detailed drawings to be produced. The treatments described and illustrated are not a comprehensive list of all possible available treatments.

Some of the abnormal circumstances that may be encountered and require special geotechnical design systems are:

- insufficient road reservation to provide safe batter slopes for cuttings
- insufficient road reservation or clearance to contain embankments requiring the use of special containment methods
- excavations with excessive flows of ground water
- embankments constructed over wet, soft or inaccessible swamp land
- situations where ground water contains too high a content of dissolved salts to allow it to be directly discharged into the surface drainage system
- situations where fill material contains harmful chemicals such as natural occurring arsenic or acid sulphates, or man-made pollutants as a result of burial of industrial waste prior to stringent controls being introduced
- embankments requiring monitoring of settlement
- materials that are easily eroded by surface water such as sands and gravels.

Designers should also obtain any local information available from road agencies, including information on the process of managing any risks associated with roadside hazards. An example of a risk management process can be found in the *Risk Management of Roadside Geotechnical Hazards* (VicRoads 2013a).

Designers should also refer to the road agency for information on the local policies and practices for slope stability treatments.

B.7.2 Slope Stability Treatments

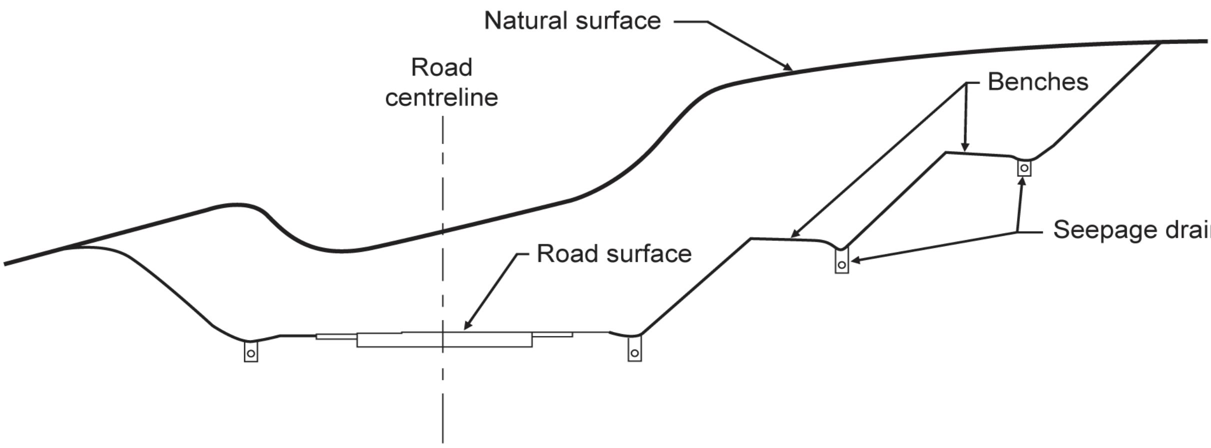
There are numerous treatments available to treat batter slopes that need to be steeper than the minimum desirable slope for the material in order to prevent land slips, falling rock or soft material from being eroded from the batter surface.

Information on the design, specification, construction and testing of these treatments may be available from the road agency. An example can be found in the *Specifications for Roadworks and Bridgeworks, Section 682: Reinforced Soil Structures* (VicRoads 2018a) and *Section 683: Soil Nail Walls (VicRoads 2018b).*

Provision of Benches on Cut Batters

A common method of improving the stability of cut batters is to provide benches between 3 m and 6 m wide in the face of the batter (Figure B 25). Benching has the effect of reducing stresses caused by lack of soil containment lower down in a road cutting. Benches also provide the opportunity to intercept water flowing down the batters by installation of concrete drains along the inside of benches to reduce erosion. Benching can also assist maintenance access and worker safety.

Figure B 25: Benching of cut batters



Soil Nailing and Rock Anchors

Soil nails

Soil nails are used to stabilise relatively low strength rock in steep cut batters by installing reinforcing rods into pre-drilled holes and grouting them into place. Soil nails are typically designed to carry passive tensile force imposed by any outward movement of the soil and are not usually pre-stressed as is the case for rock anchors (see below). The effect of soil nailing is to bind the soil structure together to form a monolithic block which acts as a retaining structure. The cut batter treated with soil nailing can be faced with reinforced sprayed concrete or other batter protection methods. To improve the aesthetic appearance in urban areas, a non-structural outer facing of tiles or brick may be used to cover the sprayed concrete surface.

Rock anchors

Rock anchors are used to bind large segments of fractured rock together in a manner similar to the way in which prestressing rods or cables are used to hold concrete segmental box girders together in a bridge structure. Steel rods or cables are installed into drilled holes in the rock face and are usually grouted into place. The section not grouted can be protected by a coating or sheath. Depending on the geology, prestressing rods or cables may need to be at a right angle to the rock bedding planes rather than at a right angle to the cut batter face. Rock anchors can be used to stabilise isolated zones of fractured rock or may be used in a grid pattern to bind large areas of fractured rock together so that it behaves monolithically and forms a retaining structure.

Reinforced Soil Retaining Walls

In urban areas, there may be insufficient road reservation or space to provide 2:1 fill batters. Fill batters steeper than this generally require a means of retaining all or part of the fill height. One method of retaining the fill involves the reinforcement of earth. Reinforced soil structures are generally lower in cost than gravity or reinforced concrete retaining walls.

The reinforced soil structure consists of interlocking concrete panels typically anchored by galvanised steel anchor straps (Figure B 26) but in corrosive environments polyethylene straps may be used. Anchor straps are placed progressively between layers of structural fill as the construction of the embankment proceeds. Structural fill must contain sufficient angular particles to provide adequate surface friction against the straps. The straps are designed to take the required tensile loading and develop sufficient pull out frictional resistance to prevent any outward movement of the interlocking concrete face panels. Concrete panels may be cast in various colours and patterns to create an architectural feature. Figure B 27 shows examples of reinforced soil retaining structures.

Figure B 26: Typical section through a reinforced soil wall

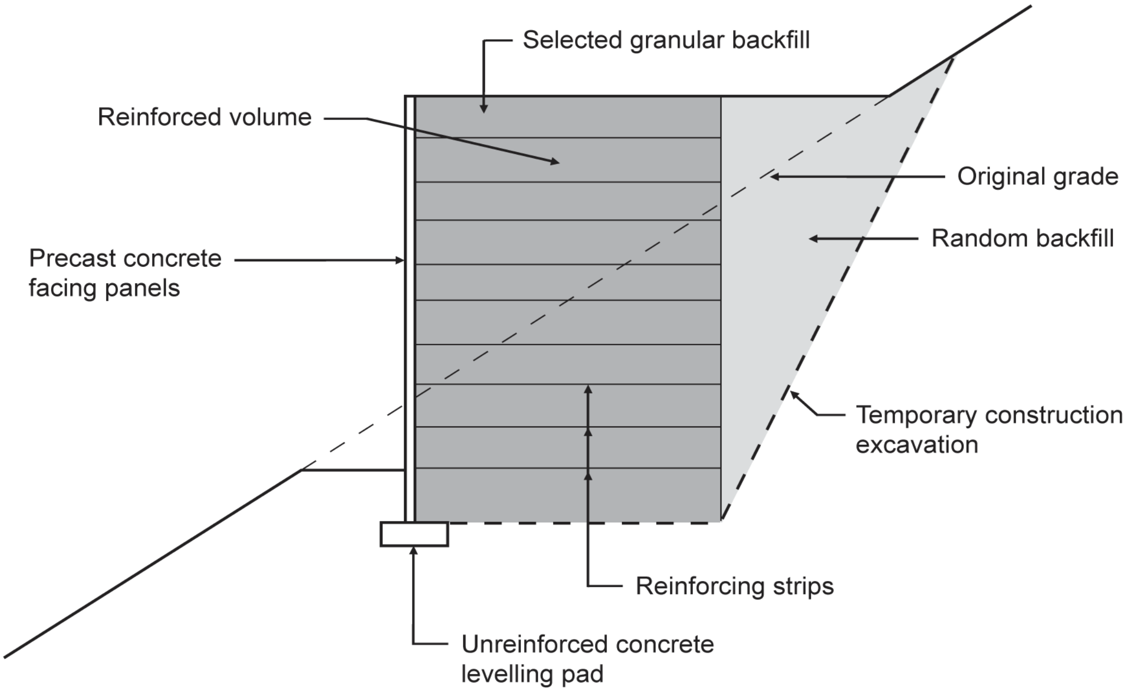


Figure B 27: Examples of reinforced soil retaining structures

Containment of a road embankment

Vertical bridge abutment

Gabion Retaining Walls

Gabions comprise clean rock spalls (ranging from 100 mm to 300 mm in size) that are contained in specially designed corrosive resistant steel mesh wire baskets. The basket units are generally stacked in a brick pattern to form a gravity retaining wall. The wire baskets also contain internal bracing with a wire mesh fold down lid at the top. Wire baskets are generally available in lengths ranging from 2 m to 6 m, widths ranging from 0.5 m to 2 m and heights ranging from 0.5 m to 2 m.

As gabion walls are gravity retaining walls each row is typically stepped or raked back to form a wall with a face angle of about 0.5:1. Gabion walls have a more natural appearance than other types of retaining wall and are generally regarded as aesthetically pleasing. Other features are that gabion walls are self-draining, simple to construct and quite versatile in application.

Crib Retaining Walls

A crib wall (Figure B 28) is typically a three-dimensional framework of interlocking 2 m long blocks or slabs of concrete or timber, filled with a rectangular cross-section of around 200 mm x 150 mm x 2 m long concrete or timber slabs, with a permeable crushed rock or gravel used to fill the void in the framework and hold the crib sections in place. The wall is intended to be self-draining. Crib walls are essentially designed as a gravity retaining wall and are raked back at an angle of about 0.5:1. The height is generally limited to about 4 m but may be increased by using a twin cell arrangement. A small amount of topsoil is sometimes added to the front face of the wall between the crib units to enable creeping plants to grow down the wall to improve aesthetics. Crib walls are also suitable to provide a temporary retaining wall that can be readily dismantled and salvaged.

Figure B 28: Example of a concrete crib wall under construction

B.7.3 Treatments for Soft or Swampy Ground beneath Embankments

General

Construction of embankments over unstable or wet swampy ground presents special design and construction challenges requiring close consultation with a geotechnical expert. Generally, special foundation treatments and construction procedures are required to enable the embankment to be constructed, to control movement and settlement, and to avoid failure of the weak foundation material.

Under these circumstances consideration may be given to:

- construction of a permeable rock raft to replace soft, wet, unstable material
- excavation of soft material and replacement with permeable sand or gravel encapsulated in a geotextile fabric, if appropriate and permeable rock fill is not economically available

- drying out the soft, wet and unstable material beneath the embankment by use of well points and wick drains outside the toe of the embankment which may be sufficient to lower the water table beneath the embankment prior to construction
- provision of a permanent fill surcharge to support the toe of the embankment that may reduce the risk of failure of the foundation beneath the toe of the embankment.

Permeable Raft Treatments

A permeable mattress can be constructed across a swampy area in a 1 m to 2 m deep face to form a sound foundation for an embankment. The mattress is usually constructed from spalls of hard clean and durable rock fill that is progressively placed from solid ground into the swamp. In order to minimise subsequent embankment settlement, it is important to progressively remove as much unstable or compressible material as practical, particularly decomposed organic material such as swamp grasses and peat. This can be done progressively by use of a hydraulic excavator or drag line and trucks using the mattress as working platform as it is extended into or across the swamp.

The rock fill mattress is required to be completely permeable and free of fine material. It achieves its stability by positive rock-to-rock contact where water can flow freely through it. Blinding layers of smaller size is used to avoid migration (piping) of any fine fill material placed over the rock mattress. A geotextile fabric may also be placed in combination with the blinding layer.

If it is uneconomical to transport rock spalls to the site, a permeable mattress may be constructed from locally available permeable dune sand or gravel. The sand/gravel mattress is constructed in a similar fashion to a rock fill mattress but requires complete encapsulation of the sand or gravel to prevent erosion and migration. A geotextile fabric wrapping is typically used to line the bottom and sides of the excavation in advance of the sand/gravel placement. A sand or gravel mattress should be immediately covered with the next layer of filling if surface erosion of the mattress is likely.

As for a permeable rock fill mattress, a sand/gravel mattress does not become unstable due to build-up of pore pressure under loading. Permeable sand/gravel materials have low soil suction (capillary action) and are designed to prevent moisture rising beyond the water level or level of the water table.

Dewatering Systems

Well points

Dewatering systems may be used to dry out an area on which fill is to be placed or to increase the stability of the material under or immediately outside the toe of the embankment. Well points comprise an outer perforated steel pipe shell driven into the ground with an inner suction pipe that is used to pump out air and water and thereby lower the water table and stabilise the area. Filter material may be placed between the outer perforated shell and the suction pipe. Well points placed each side of an over-wet embankment foundation may effectively lower the water table and stabilise the area so that construction plant is able to operate.

Wick drains

Consolidation of saturated materials beneath an embankment can be accelerated by installing a grid of prefabricated wick drains to shorten the drainage path for water being expelled from beneath the embankment. A wick drain is a geotextile lined plastic form which can be fed into a rectangular hole. It is installed beneath the embankment and must be linked to a permeable blanket to enable expelled water to escape. The spacing of wick drains is usually 1.5 m to 3 m depending on the permeability of the foundation material. Figure B 29 shows installation aspects of wick drains and Figure B 30 shows a treatment after installation.

Wick drains can reduce construction delays by shortening the waiting time required for embankment settlement to stabilise before various stages of construction can proceed. Use of wick drains limits the build-up of pore pressures in the embankment foundation reducing the risk of failure associated with excessive build up or water or in extreme cases, liquefaction of the foundation material.

Figure B 29: Installation of wick drains

Source: SoilWicks Australia.

Figure B 30: Wick drains after installation

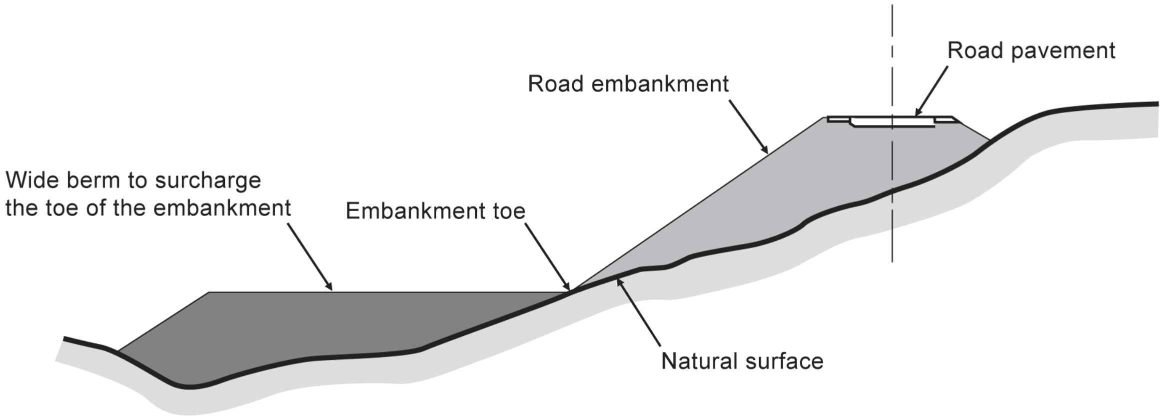
Source: SoilWicks Australia.

Surcharging

Where low embankments are constructed across wet and unstable swampy terrain, the height of the embankment may not induce sufficiently rapid settlement (particularly at bridge abutments). A relatively inexpensive way of accelerating settlement is to construct a higher embankment than is required for the final design grade line in order to provide a surcharge load that can generate more rapid settlement. Once settlement has stabilised the fill surcharge is removed and construction can be completed.

For embankments constructed over a soft, wet and unstable soil foundation, particularly those constructed on the edge of a flood plain with high ground on one side, the embankment foundation can be surcharged by placing additional permanent fill to form a wide berm (Figure B 31). The weight of the berm places downward pressure to support the toe and prevent upward movement of the wet unstable material outside the toe of the embankment. Such a measure can only be taken if the road reservation is sufficiently wide or suitable arrangements can be made with adjacent property owners.

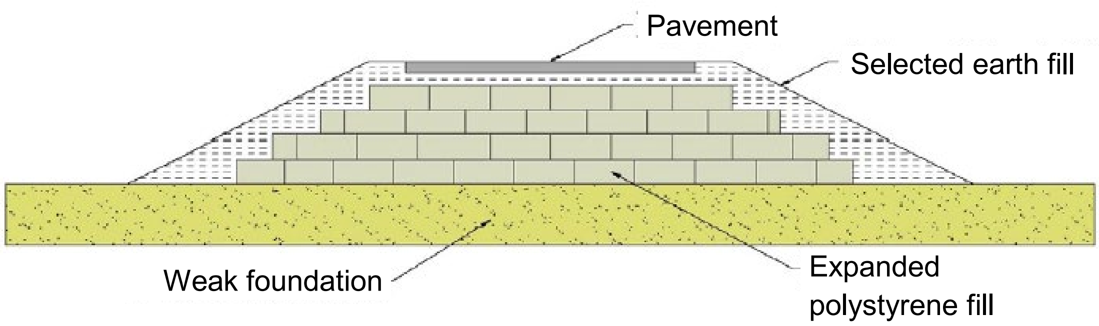
Figure B 31: Surcharge to stabilise an unstable embankment toe



Lightweight Fill

For low embankments constructed across weak, over-wet foundations, consolidation and settlement can be reduced by use of expanded polystyrene (EPS) blocks placed in a brick pattern in the core of the fill (Figure B 32). EPS blocks are only a fraction of the weight of normal fill material and result in a significant reduction in stress on the embankment foundation. There is much reduced or no delay to construction as is the case with prolonged consolidation of conventional fill and the need for surcharging is avoided.

Figure B 32: Typical cross-section of lightweight fill embankment



Source: VicRoads (2006).

It is necessary to encapsulate the EPS blocks with a free-flowing material (e.g. sand) and to protect them with sufficient capping material prior to construction plant traversing the lightweight embankment. Cement stabilised crushed rock is often used for this purpose because of its ability to spread loads. EPS blocks are produced in various sizes and with various internal compressive strengths but should be placed above maximum possible flood or inundation levels to avoid any possibility of flotation. Whether or not flotation is an issue depends on the volume of the blocks, compared to the volume of fill and pavement material placed above it and how the blocks are encapsulated.

EPS blocks may be used in steep topography where land slips have occurred or embankments have been washed away. Access is usually very difficult and restoration works using the blocks can provide advantages over other options due to their lightweight. The blocks are placed in a brick pattern and can be used in combination with a very light post and geotextile lined wire mesh retaining structure. The method is a more rapid and less environmentally intrusive method of repair than attempting to use more substantial retaining walls to retain an imported fill embankment.

B.7.4 Monitoring of Movement in Embankments

The geotechnical investigation should identify the ground conditions where movement of embankments is likely to occur. A suitably qualified and experienced geotechnical engineer will be required to make predictions of the likely settlement, initially based on laboratory consolidation testing. Estimates of consolidation will identify those embankments that may be more prone to settlement and movement and which will require monitoring of movement during construction.

Estimation of the amount and rate of settlement (consolidation) from laboratory tests prior to construction is usually regarded as indicative only. To provide a more accurate prediction of the amount of movement or consolidation, it is necessary to monitor the horizontal and vertical movement of the embankment as construction proceeds and is particularly important for embankments at bridge abutments. In some cases, monitoring of embankment settlement may force a delay in the commencement of pavement and structural works until such time as all movement has stabilised. If excessive movement is measured during the course of embankment construction, a cessation of construction may be required to enable movements and pore pressure under the embankment to stabilise before further filling is added. Movement during embankment construction is typically monitored using:

- inclinometers placed in a cylindrical casing to measure the horizontal movement in the embankment
- settlement cells installed within the foundation material supporting the embankment to measure the vertical movement
- piezometers to measure pore pressure in foundation material supporting the embankment and thus provide warning of excessive build-up of pore pressures that can cause the fill foundation to become unstable and prone to shear failure
- permanent survey marks installed after completion of embankments that do not require instrumentation.

Planning for fill settlement and movement is an important consideration as it could result in delays to critical parts of the project such as a major structure. Conversely, if movements are smaller than expected, pre-planned waiting periods associated with embankment construction, or delays to commence structural or pavement works, may be reduced or eliminated.

B.7.5 Erosion Protection

The geotechnical investigations should identify materials that are prone to significant erosion. Materials with little or no cohesion such as dune sand are particularly vulnerable. Unless batters or grades are very flat, additional preventative measures will need to be considered.

It is important to re-establish vegetation as soon as practicable. To provide additional protection topsoiling may be supplemented by:

- spraying batters with additional seed, fertiliser and bitumen/straw mulch
- placing biodegradable matting or mesh that allows the passage of light and air and prevents erosion prior to establishment of seeding
  Grasses re-establish under the matting which decomposes over time.
- using straw thatching anchored down with wire.

Open drains constructed in erosion prone materials, may be treated with:

- rock beaching or concrete lining
- rock walls to allow grades to be reduced
- reinforced concrete drop structures and energy dissipaters
- straw and wire thatching.

Figure B 33 shows some typical treatments to prevent erosion.

Further information is provided in Austroads (2013b).

Figure B 33: Typical erosion prevention treatments

Batter treatment

Straw wire and plants

Rock weir

Fabric matting

B.7.6 Contamination

Ground Water Containing Dissolved Salts

If the geotechnical investigation identifies that ground water intercepted in cuttings contains higher than normal amounts of dissolved salts and minerals, the local environment protection agency may not permit ground water to be discharged directly into a watercourse unless the water has been treated. The treatment required will depend on the amount of dissolved salts present in the ground water and the flow rate of the stream to which salty water is being discharged.

To permit direct discharge into rivers and streams, the usual method of treating water with a salt content exceeding the limit is retention and dilution. Salty water may be piped to an artificial wetland feature or retarding basin (Figure B 34) where it is mixed with fresh drainage water prior to discharge. Salty water may require longer retention at times when there is a low flow of fresh water into the retarding system or there is low flow in the watercourse into which salty water is to be discharged.

Figure B 34: Treatments for run-off water

Roadside wetland

Roadside wet detention basin

Contamination Investigation

General

It is important that geotechnical investigations identify the extent and depth of any contaminated material that is likely to be excavated or exposed. Fieldwork for these types of investigations may be combined with geotechnical investigations for economic benefits and reducing the site disturbance.

Contamination may be from man-made activities such as waste burial or past industrial activity such as cyanide used for gold extraction, or more commonly they may be naturally occurring acid sulphate soils or arsenic which can become a significant problem when exposed to air and water. Contaminated materials, ground water and runoff need to be contained to prevent their escape into the environment.

It is preferable that the design is such that it is possible to avoid excavation and exposure of soils containing harmful contaminants. However, if this is not feasible, special treatments or procedures will be required.

Acid sulphate materials

One of the more common problems is the presence of acid sulphate materials, soils and rock, often found in coastal areas of Australia that have been previously inundated by the sea. When exposed to air, the iron sulphides contained in the material oxidise to produce sulphuric acid. Once formed, sulphuric acid can be leached from the soil by water in concentrations that are harmful to most forms of vegetation and fish. Sulphuric acid is also extremely corrosive.

Acid sulphate materials are found in the coastal areas of the Northern Territory, Queensland and New South Wales but also have been found around Perth (WA), Adelaide (SA) and Westernport (Vic). Some states/territories have geological maps showing the location of acid sulphate materials.

If excavation or disturbance of acid sulphate soil by earthworks and trenching activities is unavoidable, the material should be removed and covered as quickly as possible either by encapsulation within an embankment or buried in an approved manner. Under no circumstances should acid sulphate material be stockpiled and exposed to air for a prolonged period. Methods of dealing with acid sulphate materials will become part of an environmental management plan after consultation with the local environment protection agency.

More information on acid sulphate materials may be available from road agencies. Examples of the information available can be found in Roads and Traffic Authority (2005) and VicRoads (2013b).

Arsenic-contaminated soils

Soils containing natural arsenic have been found near mineral deposits in Australia particularly in the gold mining regions of Victoria. Arsenic can be leached out of the soil by ground water and into the general environment if not contained. Soils containing arsenic are generally found in relative small volumes which can be readily treated and removed. One such treatment is the addition of a cementitious binder to neutralise the arsenic prior to disposal of the contaminated soil in a manner approved by the local environmental protection agency.

Naturally occurring asbestos

Asbestos occurs naturally in the environment and may affect the delivery of a project. To assist in identifying potential locations where this type of asbestos may occur some agencies may have access to information such as in NSW, where mapping of potential locations has been undertaken and published in Heads of Asbestos Coordination Authority (2015).

Guide to Road Design Part 1: Objectives of Road Design provides practitioners with a detailed description of the critical aspects of road design. This Part includes the design objectives that apply to a road design project, design philosophy, context-sensitive design and the factors that influence the road design, including road design in the context of the Safe System approach, the design domain concept, design phases and processes, design considerations, design and legal liability, delivery considerations and emerging technology considerations.

Guide to Road Design Part 1

Austroads

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