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GROUND ANCHORS:
DESIGN AND CONSTRUCTION GUIDELINE

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1 GLOSSARY OF TERMS

Acceptance Test: Incremental loading of a prestressed anchor recording the total movement of the anchor at each increment.

Anchor: Geo-structural elements, installed in soil or rock, that transmit an applied tensile load into the ground to provide load restraint, manage deflections and/or improve stability of engineered systems.

Anchor Designer: The suitably qualified engineer who leads the anchor system design. More complex anchor design projects may have a geotechnical and structural engineer working on the design with split responsibilities.

Anchor Head: The means by which the tension in the tendon is transmitted to the bearing plate. The anchor head includes wedges and a wedge plate for strand tendons or an anchor nut for bar tendons.

Anchor Nut: The threaded device that transfers the prestressing force in a bar to a bearing plate.

Apparent Free Length: The length of tendon which behaves as if it were not bonded to the surrounding grout or ground, as calculated from the elastic extension data during load testing.

Bond Length: The length of the tendon that is bonded to the primary grout and capable of transmitting the applied tensile load to the surrounding soil or rock.

Bond Breaker: A sleeve placed over the anchor tendon in the design free tendon length to avoid load transfer from the tendon to the ground.

Centralizers: Centralizers are commonly made from plastic and are used to support the tendon in the drill hole or within an encapsulation sheath so that a minimum grout cover is provided around the tendon or tendon pre-grouted within a sheath.

Collapse Avoidance Limit State (CALS): Waka Kotahi New Zealand Transport Agency Bridge Manual term that states: After an event with a return period greater than design (DCLS) value, the structure should not collapse, although damage may be extensive.

Contractor: The person/firm responsible for performing the anchor work.

Corrosion inhibiting Compounds: These compounds are used to fill the cavities in and immediately behind the anchor head to protect steel components of the anchorage, are nonhardening, and include greases and waxes.

Coupler: The means by which the prestressing force can be transmitted from one partial-length of a prestressing tendon to another (mainly for bars).

Creep Movement: The movement that occurs during the creep test of an anchor under a constant load.

Creep Test: A test to determine the movement of the ground anchor at a constant load.

Damage Control Limit State (DCLS): Waka Kotahi New Zealand Transport Agency Bridge Manual term states: After exposure to a seismic event of design (DCLS) severity, the structure shall be usable by emergency traffic within three days, although damage may have occurred, and some temporary repairs may be required to enable use by vehicles. (Equivalent to ULS)

Design Load (DL): Anticipated final maximum effective load in the anchor after allowance for time-dependent losses or gains. The design load includes appropriate load factors to ensure that the overall structure has adequate capacity for its intended use.

Elastic Movement: The recoverable movement measured during an anchor test.

Encapsulations: Encapsulations are corrugated, or deformed pipe or tube filled with grout that protects the tendon in the bond and / or free lengths.

1 GLOSSARY OF TERMS

Free Stressing (Unbonded) Length: The designed length of the tendon that is not bonded to the surrounding ground or grout during stressing.

Grout: Grout protects the tendon in the unbonded and bonded lengths and may either be cement-based or polyester resin. Polyester resin grout is not generally considered to provide a corrosion protection layer, as gaps in the resin coverage will leave the tendon unprotected. Grouts are also used to fill sheaths, encapsulations, covers, and trumpets.

Heat Shrink Sleeves: These sleeves are mainly used to protect couplers that connect lengths of prestressing bar and sometimes as sheaths for bar tendons. They are also used to protect the transition from the free length to bonded length of strand tendon.

Investigation Test: Incremental cyclic test load of sacrificial anchor to confirm grout-ground bond strength.

Lift-Off: The load (lift-off load) in the tendon which can be checked at any specified time with the use of a hydraulic jack, by lifting the anchor head off the bearing plate.

Lock-Off Load: The prestressing force in an anchor immediately after transferring the load from the jack to the stressing anchorage.

Maximum Credible Earthquake (MCE): The maximum credible earthquake expected for a structure, used for some critical infrastructure design situations.

Multi-Strand Tendon: An anchor system where multiple small diameter steel strands are tethered together to form an anchor system.

Permanent Anchor: Any prestressed ground anchor that is intended to remain and function as part of a permanent structure. A permanent anchor has to fulfill its function for an extended period of time and thus requires special design, corrosion protection, and supervision during installation.

Suitability Test: Incremental cyclic test loading of a prestressed anchor in which the total movement of the anchor is recorded at each increment.

Relaxation: The decrease of stress or load with time while the tendon is held under constant strain.

Residual Movement: The non-elastic (i.e., non-recoverable) movement of an anchor measured during load testing.

Serviceability Limit State (SLS): The state beyond which a structure becomes unfit for its intended use through deformation, vibratory response, degradation or other operational inadequacy. Regularly used for NZ Building Code designs.

Sheaths: Sheaths are smooth or corrugated plastic tube, smooth pipe, or extruded tubing used to protect the tendon in the free (unbonded) length. Individual strand sheaths commonly contain corrosion inhibiting compound and are either pulled-on or extruded. A tendon sheath covers all tendon elements and is commonly pulled-on and pre-grouted. Smooth sheaths are used as a bond breaker, and corrugated sheaths are used ensure a good bond with the grout.

Tendon: The structural core of the anchor system and providing continuity for load transfer from the anchor head to the grouted anchorage length.

Test Load (TL): The maximum load to which the anchor is subjected during testing.

Trumpet: The trumpet protects the back of the bearing plate and tendon in the transition from the anchorage to the free stressing length and is fabricated from steel or PVC pipe.

Unconfined Compressive Strength (UCS): A simple test where the maximum load that can be sustained prior to failure and is determined from an unconfined cylinder of material.

Ultimate limit state (ULS): The state beyond which the strength or ductility capacity of the structure is exceeded, or when it cannot maintain equilibrium and becomes unstable. Regularly used for NZ Building Code designs.

Wedge: The device that transfers the prestressing force in the strand to the wedge plate.

Wedge Plate: The device that holds the wedges of multistrand tendons and transfers the anchor force to the bearing plate.

Working Load: Equivalent term for Design Load.

2 INTRODUCTION

Ground anchors are geo-structural elements, installed in soil or rock, that transmit an applied tensile load into the ground to provide load restraint, manage deflections and/or improve stability of engineered systems. The aim of this guidance document is to promote consistency of approach in engineering practice in the design, construction and maintenance of ground anchors in New Zealand.

In this document

- **Section 2** provides an introduction to the types of ground anchors and their components.
- **Section 3** provides guidelines for design of ground anchors for a range of different types of structures within the framework of NZ performance-based design practice.
- **Section 4** provides detailing of corrosion protection of ground anchors to meet durability requirements reflecting the importance of the anchor detailing to satisfy long term performance expectations.
- **Section 5** provides general considerations for construction and testing of ground anchors.
- **Section 6** provides guidance for post construction inspection and monitoring processes to support long term design and performance objectives.
- **Appendix A** provides a list of international references.
- **Appendix B** provides example calculations for some selected ground anchor applications.
- **Appendix C** provides a recommended anchor test loading schedules.
- **Appendix D** provides some historical testing bond strength testing results for common New Zealand rock and soils.
- **Appendix E** provides typical anchor details. CAD files of typical anchor design details are included on the NZGS website.
- **Appendix F** provides a checklist for pre-design, design and construction phases of an anchor design project.
- **Appendix G** provides an example design coordination statement for building consent submissions.

Irrespective of the diligence applied in the design, the influence of the skills of the construction professionals on the performance characteristics of the completed anchor system cannot be over emphasised. This sensitivity of the anchor performance to the quality of the construction processes, allied to the vagaries of geotechnical design, necessitates that all anchor designs are presumptive until proven and finalised following site-specific anchor testing.

APPLICABILITY

This module provides guidance for the planning, design, construction, testing and maintenance of ground anchors which are commonly used in New Zealand. Users of the document are assumed to be qualified, practicing geotechnical engineers and construction professionals with sufficient experience to apply professional judgement in interpreting and applying the recommendations contained within this document. Complex, high risk, and unusual design situations are not covered here. In these cases, special or site-specific studies are considered more appropriate, and the reader is referred to established and recognised references such as those presented in Appendix A.

Whilst this module focusses on ground anchors with the pull-out resistance generated by a grouted interface with the soil or rock it is recognized that proprietary mechanical systems also exist. For completeness, brief descriptions of these alternate systems are presented in Section 3.2.4.2. However, the designs for these systems are often subject to proprietary installation processes and may be subject to bespoke analysis and/or empirical design methodologies which may rely, to greater or lesser extents, on databases of field and control tests, and are beyond the scope of this guide.

This module does not cover:

- **Application** – how the anchors are used for specific situations such as retaining walls, foundations and slope stabilisation, for which reference should be made to other appropriate guidance documents.
- **Derivation of loads** – loads that are carried by the anchors will come from the design of structures, retaining walls, foundations, slopes, rock wedges, tunnels etc.
- **Complex anchor systems** - special anchors designed for specific complex or high-risk structures (for example restraint of wind turbine bases under sustained cyclic loading, or where anchors may be subject to shear and bending loads in addition to tension).
- **Pull-out resistance** where the ground is susceptible to liquefaction or cyclic softening.
- **Soil nails** (however it is acknowledged that some of the general information and construction principles can also be translated to soil nail applications).
- **Structural anchors** – the anchors that are used entirely as part of the structure and do not rely on the ground-grout bond to generate load resistance or rely on passive earth pressure to derive its resistance (for example deadman anchors or wall to wall anchors).
- **Tension piles** (taken here as ‘rigid’ structural elements that may resist compression and tension loads or tension loads with no debonded elements)

3 NZ FRAMEWORK FOR ANCHOR DESIGN

The New Zealand Building Act: 2004 requires that all building work must comply with the New Zealand Building Code (the Code) regardless of whether a building consent is required. The Code is a Performance Based approach, prescribing the functional requirements for buildings and the performance criteria with which buildings must comply in their intended use:

- **Clause B1** covers Structural performance, in particular:
  - Safeguarding people from the effects of structural failure.
  - Safeguarding people from loss of amenity caused by structural behaviour.
  - Protect other property from physical damage caused by structural failure.
- **Clause B2** covers durability performance, in particular:
  - Materials, components and construction methods are to be sufficiently durable to ensure that the building, without reconstruction or major renovation, satisfies the other functional requirements throughout the life of the building.

Clauses B1 and B2 of the Code provide prescriptive methods or solutions (referred to as Verification Methods and Acceptable Solutions, respectively) that can be used to demonstrate compliance of a design to the Building Code. As no prescriptive methods are available, that can be used to explicitly demonstrate compliance of an anchor design within Clause B1 of the Code, anchor designs are by default 'Alternative Solutions'. Alternative Solutions require designers to demonstrate, to the satisfaction of the Building Consent Authority (BCA), that a design solution does achieve the performance requirements of the Code. This guide is intended to support designers in the demonstration of compliance with the requirements of the Code.

Introductory commentary on the stability and durability requirements with respect to ground anchors, covered by Clauses B1 or B2 respectively, are presented further in the following sections.

3.1 CLAUSE B1 (STRUCTURES)

The industry approach to ground anchor design (for example by reference to the British Standard Code of Practice for Grouted Anchors (BS8081), Federal Highways Authority Geotechnical Engineering Circular No. 4, Ground Anchors and Anchored Systems (FHWA), or the Waka Kotahi New Zealand Transport Agency Bridge Manual (BM)) is relatively unique within geotechnical practice as it explicitly requires sacrificial anchor tests to validate the initial (presumptive) ground-grout bond design parameter values. Further, all anchors constructed for permanent and temporary works should also be subject to acceptance tests. These tests provide actual, site specific anchor performance characteristics (load capacity, load-deflection responses and creep) which can be used to directly demonstrate compliance of the design with the performance expectations.

New Zealand is a seismically active country, and estimations of earthquake hazards and loads are always associated with significant uncertainties. It is notable for anchor design that the geotechnical component of the anchor resistance (i.e. ground-grout and cone-wedge mechanisms), together with the grout to tendon capacity, can be of a brittle nature whereas the structural resistance can (with appropriate detailing) be ductile. This variation in ductility is particularly important given the significant uncertainty as to seismic loads from earthquakes and post-seismic life safety and functionality considerations. Therefore, ground anchor systems should be designed with the ductile performance of the tendons governing the seismic response.

3.2 CLAUSE B2 (DURABILITY)

Most permanent anchors for buildings will have a design working life of not less than 50 years, however this may vary depending on structure importance level. Temporary anchors used during construction may have shorter design lives (months or weeks, and some circumstances a few years) whereas permanent anchors used for infrastructure often have a design working life of not less than 100 years. These design durations need to be part of the design brief agreed with the client and clearly identified in the building consent application.

The Acceptable Solutions and Verification Methods within Clause B2 do not cover all possible combinations, uses and conditions which may be applied to a building element. For ground anchors, verification of compliance with durability requirements will therefore be by proof of performance and should take into account the expected in-service exposure conditions. Considerations should include comparable performance of similar building elements, published (or project specific) test data and in-service history. Inspection and maintenance regimes over the service life of the facility supported by the anchors should therefore be considered in the design of the anchor system, noting that many anchors can often be very difficult to access (such as on slopes or retaining walls, or within basements with limited post-construction access).

It should be recognised that residential owners may not have the knowledge or capability to maintain the ground anchors. Therefore, the detailing of anchor systems should minimise the need for maintenance.

An inspection & maintenance regime and an anchor replacement methodology (if envisaged in the design) must be adequately recorded and communicated to the owners, facility operators and maintenance engineers (through maintenance instructions/schedules, Safety in Design Registers and/or through BIM processes).

3.3 LOAD RESISTANCE AND DEFORMATION PERFORMANCE

This guide does not provide for derivation of the loads the anchors must be designed to safely resist, nor the deformation requirements, both of which will be application specific. The structural design performance requirements should therefore be explicitly agreed and communicated between the structural and geotechnical engineers.

The anchor loads, and load combinations (considering serviceability and ultimate limit actions) derived for use with this guide should be factored using the standards appropriate for the design, for example the relevant New Zealand Standards or the BM. It is noted that whilst the derivation of load and load combinations within the New Zealand structural design actions standard NZS1170:0:2002 (NZS1170) does not specifically require load combinations including earth pressure and earthquake actions, it will generally be necessary to consider such combinations to fulfil the objectives of Clause B1 of the Building Code.

Acceptable levels of deformation in different situations are key considerations in the selection and design of anchor systems to resist the applied loading. Deformation must be consistent with the application of the anchors[1] and should not cause unacceptable loss of load or degradation of the performance of the overall structural system.

3.4 ROLES AND RESPONSIBILITIES

Design, construction and maintenance of ground anchor projects involves many specialisations for different components of design. This section is to provide guidance to designers and BCAs on what documentation should be produced to support a building consent (if required). The typical responsibilities of different disciplines for a medium to high complexity project is summarised in Table 3-1 below:

[1] Pre-stressed (Active) anchor systems should be used where it is important to minimise the load or the deformation of the structure; passive anchor systems (normally a nominal load is applied to remove any slack in the system) are normally used where post-construction in service deformation is acceptable and sometimes beneficial.

Table 3-1: Roles and responsibilities for ground anchor design projects

ROLE	RESPONSIBILITIES	OUTPUTS
Geotechnical Engineer	• Determination of ground conditions and derivation of geotechnical soil parameters. • Anchor system analysis and design for walls where loads are a result of geotechnical mechanisms, or soil-structure interaction modelling when undertaken in collaboration with structural engineers • Where critical, design of construction sequencing in collaboration with structural engineers and constructors • Anchor bond capacities • Settlement and effects around structures • Static/live/seismic design loads • Construction monitoring • Maintenance requirements	• Design report/calculations • Construction drawings • PS1 (geotechnical) • Construction report • PS4 (geotechnical)
Structural Engineer	• Structural component design (anchor tendon, anchor head, wall/mesh facing) • Where critical, design of construction sequencing in collaboration with geotechnical engineers and constructors • Anchor system analysis and design where loads are a result of structural actions, or soil-structure interaction modelling when undertaken in collaboration with geotechnical engineers • Construction monitoring • Maintenance requirements	• Design report/calculations • Construction drawings • PS1 (structural) • Construction report • PS4 (structural)
Component Manufacturers	• Compatibility of material components • Publication of certified load capacities and durability performances of the components and the system of components	• Material and component certification
Specialist Anchoring Constructor	• Inputs during conceptual design to ensure appropriate systems and compatibility with construction constraints are met • Anchor investigation tests • Installation of anchors • Suitability/acceptance tests • Fixing anchors to wall/mesh facing • Maintaining anchors • Implementation of construction sequencing as defined by the geotechnical or structural engineer • Construction methodology in collaboration with geotechnical and structural engineers	• Anchor test results • Construction and as-built records • PS3 (construction) • Construction methodology
Client	• Scheduling maintenance of anchor system • Responsible for records maintenance and communication of roles and responsibilities (inspection, testing and maintenance) to new owners, operators and maintenance teams • Specify design life and post seismic performance expectations where performance beyond the Building Code is required.	• Implementation of inspection and testing regimes specified by the designers • Maintenance of BIM records

Anchor design shall be carried out by engineers competent in the design of ground anchors of appropriate complexity and constructed by contractors with experience in the construction of the types of ground anchors. In some more complex projects, the roles and responsibilities for design and construction monitoring may be shared between the engineers involved with the project. Typically, a lead designer (either Geotechnical or Structural Engineer) would carry out the design with the input from the other discipline. If the PS1 from the lead designer has design aspects which are excluded, these design aspects must be covered in a separate PS1 by the collaborating engineering firm. In such cases, the provision of a "design co-ordination statement" (by letter or email correspondence) alongside the Producer Statement signed by lead engineering discipline would be appropriate to demonstrate to a BCA that such co-ordination has taken place. Alternatively, if the lead designer covers all aspects of the design in their PS1 but relies on a different engineering firm to conduct inspections or verification during construction, confirmation from the designer's site representative (by letter or email correspondence) that they are familiar with the design would be suitable to support the building consent application.

A peer review is appropriate for complex and high-risk anchor projects. If there are any questions regarding the possible requirement for a 'Producer Statement – PS2 Design Review', the designer may contact the relevant consenting authority for guidance. Where peer review is completed, a copy of the comment register and PS2 should be supplied to the BCA. Where included, a peer reviewer should be incorporated in the "design co-ordination statement". An example of a design co-ordination statement is provided in Appendix G.

4 GROUND ANCHOR TYPES AND COMPONENTS

4.1 TYPES OF ANCHORS

Ground anchors are structural members that generate resistance to tension loading by securing a tendon into rock or soil. They are typically deployed to support retaining walls, slopes, foundations, tunnels or resist applied structural loads. The application and performance requirements of ground anchors may vary widely. They can often be found in the following configurations:

- Pre-stressed ('active') anchors in rock and soil- used to restrain movement and resist loads.
- Unstressed ('passive') anchors in rock and soil - used to resist loading used in situations where the inherent deformation is acceptable.
- As tiebacks (stressed or non-stressed) to deadman anchors or between back-to-back retaining walls (design of both uses not covered here).
- Rock bolts (stressed or non-stressed).

Rock bolts are a particular type of drilled and grouted anchor and are used to stabilise jointed and fractured rock masses. They are distinguished from other anchors in that they can also contribute to restraining rock faces by preserving the contribution of mechanical interlock at joint interfaces (not covered in this guide).

The selection of the anchor system (tendon, head componentry, corrosion protection) will be dependent on performance requirements, including consideration of its design working life, risk (environmental exposure and performance) and whether it needs to be re-stressed and/or de-tensioned.

4.2 ANCHOR COMPONENTS

The ground anchor can be broadly divided into four components, with each component providing a distinct functional contribution (with different design and construction considerations) to an overall anchor installation. These components (illustrated in Figure 2.1 below) are the anchor tendon, the anchor head, the free length (unbonded) and the bond length.

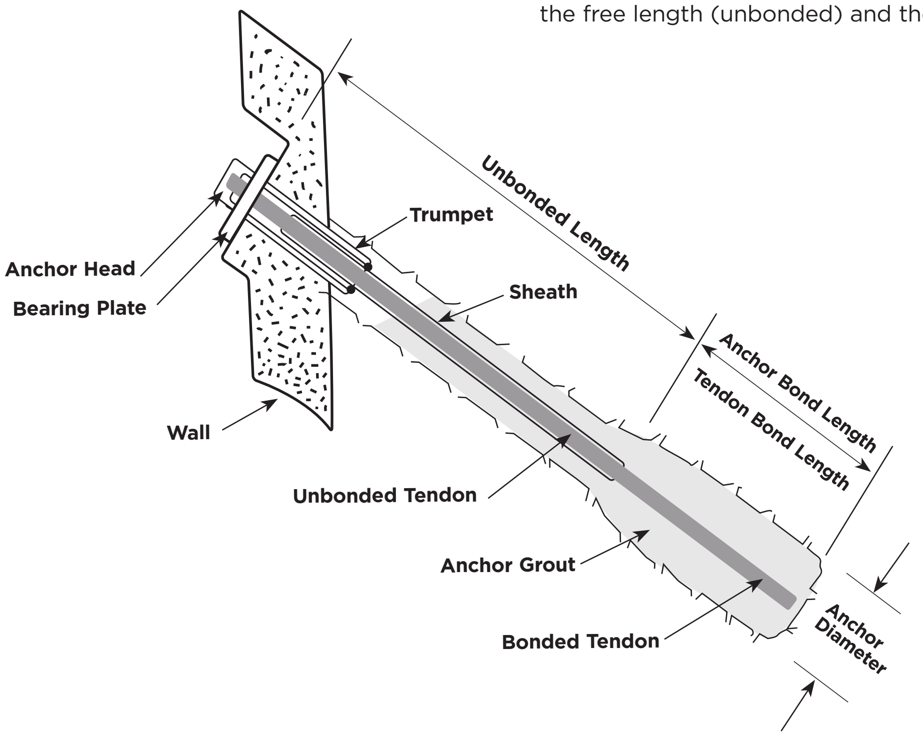


FIGURE 4.1: Components of a grouted ground anchor system

4.2.1 TENDONS

Tendons are the structural core of the anchor system and provide continuity for load transfer from the anchor head to the grouted anchorage length. Tendons are commercially available as single or multiple steel pre-stressing strands or as rigid bars (solid steel, hollow steel or solid Glass Reinforced Plastic (GRP)).

Steels of various grades along with cementitious grouts are typically the primary tendon materials adopted within a ground anchorage system. Inert materials such as GRP or stainless-steel tendons can also be used. All components, grout, and compounds in contact with the tendon or hardware should be checked for compatibility (e.g. bi-metallic corrosion or chemical attack) and must be capable of providing the desired design working life of the anchor system.

4.2.1.1 Solid steel bars

Steel bars can encompass a range of strength grades, typically ranging from 500 MPa steel bars to 1030 MPa stress bars. Stress bar anchors are typically found in high load applications whereas 500 MPa grade steel bars are common in low stress situations. Where space constraints limit bar tendon lengths, couplers may be used to extend the tendon length. However, consideration needs to be given to where the coupler is located relative to the free/bond interface, and its corrosion protection.

4.2.1.2 Hollow bars

Proprietary hollow bar tendons, fitted with sacrificial drill bits and with the steel tendon acting as the drilling rod, are referred to as self-drilling anchors where they are drilled and grouted in a continuous operation.

Self-drilling anchors are useful in collapsible ground, avoiding the need for temporary casing of the drill hole. Hollow bar tendons can offer the option for a limited prestress through the inclusion of debond sleeves between the couplers. This debonding is achieved through either wrapping with tapes impregnated and coated with petrolatum-based compounds or encapsulating in smooth bore tubing. De-bonding sleeves cannot generally be installed over the couplers.

Durability may be limited by inability to provide effective corrosion protection, and this should be carefully considered.

4.2.1.3 Strand anchors

Steel strand is versatile due to its flexibility with respect to transport and handling considerations.

A broad range of strand configurations (Number of strands and diameter) are available to match a range of load resistance requirements. Tendon steels have sufficiently low relaxation properties to minimise long-term anchor load losses. However, the strands are generally brittle compared to the more ductile bars available.

Theoretically, anchors using multiple strand tendons have no load or anchor length limitations but in practice are constrained by practical construction limitations, including the drill hole diameter.

4.2.1.4 GRP Tendons

GRP tendons can provide a viable alternative to conventional steel tendons. The durability of the material results in a much simpler anchor detail to achieve the same design working life, and the lighter weight facilitates handling where access is difficult. GRP bars have the following limitations:

- Ultimate capacity is often limited by the fixing shear capacity of the anchor head detail and internal bar connectors.
- Require appropriate strength reduction factors for long term creep (typically provided by supplier).
- GRP bars are brittle compared to steel, and care should be taken when used in flexure failure mechanisms or when ductility is required to cater for seismic or overload load cases.
- They are susceptible to deterioration due to ultraviolet rays and fire damage.

GRP bars are widely used in underground tunnelling and mining applications due primarily to their ease of handling, electrically non-conductive properties, and durability. They have been used in numerous tunnel projects for temporary support, in particular within zones which are to be subsequently excavated (they are more readily cut compared to steel bolts and lessen the risk of damage to plant when encountered during excavation).

4.2.2 ANCHOR HEAD

The anchor head is the load transfer element that transmits the load from a structure (and/or a pre-stress) to the anchor tendon. It typically comprises a plate and mortar pad which bears on the ground or structural member with a mechanical locking device (e.g. nut) attached to the head of the tendon. The anchor head permits stressing and locking-off of the tendon.

The anchor head components include a bearing plate, a locking nut (bar anchors) or wedge plate (strand anchors) and the length of the tendon between the anchor head and the free length.

The anchor head and the area immediately below the anchor head is typically the most vulnerable to corrosion and particular attention must be paid to the detailing of this element (described further in the Section 6). A grouted 'trumpet' detail, which protects the back of the bearing plate and tendon in the transition from the anchorage to the unbonded free length (fabricated from steel or other suitable materials), is commonly required to ensure durability of the installed components.

The anchor head should be designed to allow the tendon to be tensioned without damage and tolerate angular deviations of ±5° from the axial alignment of the tendon.

An anchor head cap may be used to protect and encapsulate the exposed anchor head lock nut and tendon. In areas of high groundwater pressure, specific drainage or sealing measures may be required around the anchor head.

4.2.3 FREE LENGTH

The free, or the unbonded length, is that portion of the anchor tendon that is free to elongate elastically and transfer the tension directly from the anchor head to the bond length. Considerations for the detailing and dimensioning of the free length include:

- Enabling stressing and testing of anchors.
- Providing flexibility and ductility in seismic load situations.
- Maintaining the serviceability and stability performance requirements (in particular the bond length is located beyond the active wedge and any critical global failure mechanism).
- Ensuring the load transfer pathways does not cause disturbance to other structures or utilities.

A minimum unbonded length of 3 m for bar tendons and 5 m for strand tendons should be adopted. These minimum unbonded lengths are required to avoid unacceptable load reduction resulting from seating losses (thread bedding or wedge draw) during load transfer and prestress losses due to creep in the prestressing steel or the soil. The free length should also extend beyond potential failure envelopes, and 0.2 x the wall height for tied back walls (whichever is greater in this instance).

Unrestrained elongation along the free length is achieved using a bond breaker arrangement between the tendon and the encapsulating grout. This arrangement typically comprises a smooth plastic sleeve placed over tendons to prevent the tendons from bonding to the surrounding grout and ground (see also Section 5, corrosion protection).

4.2.4 BOND LENGTH

The bond length is that portion of the anchor through which load is transferred to the surrounding soil or rock. The bond length resistance is generally developed through a grout to soil/rock interface.

4.2.4.1 Grouted Anchors

The grout used to transfer the load from the tendon to the parent soil, or rock, typically uses Ordinary Portland Cement (OPC). The chemistry of the grout should be checked to ensure no sulphides, nor any other elements aggressive to any of the components, are present (cements of blast furnace origin should not be used).

Gravity grouting is the most commonly adopted construction process in New Zealand practice. Alternate drill and grouting systems, beyond the scope of this guide, are also available to enhance the pull-out capacity at the grout to soil/rock interface. Generally, a minimum anchor inclination of 15 degrees is required for gravity grouting and hole stability.

The load capacity of the bond length is commonly limited by the strength of the grout to soil/rock interface and is critically dependent on both the ground characteristics and the quality of the construction processes. It is therefore imperative, in all but the lowest risk applications of ground anchors, that the bond strength adopted for grouted anchor design is established through site specific testing. Design bond strengths adopted during preliminary sizing of anchors should therefore be considered as presumptive values only, until proven by site specific anchor testing.

4.2.5 NON-GROUTED ANCHOR SYSTEMS

There are several non-grouted ground anchor solutions that can fulfil the load resistance function of a grouted bond length. Whilst not covered in this module, brief details are outlined below. The reader should refer to alternate texts, resources or specialist contractors for the design of these elements.

Tipping Plates

Tipping plate anchors comprise an eccentrically hinged head plate located on the end of a steel rod. Once pushed into the ground, the head plate rotates when tensioned to generate passive resistance by soil bearing on the head plate. Tipping plate anchors may be pushed into suitable soils but not rock or soils that are dense or hard, or contain obstructions (e.g. boulders, tree trunks/stumps). One advantage of the tipping plate anchors is that they are proof tested by the installation process.

Mechanical Anchorage

Mechanical anchorages are used in tunnels, for example through expansion of a conical insert anchorage to anchor into the surrounding rock (or soil).

Ballistic Nails

Ballistic nails are a type of soil nail where steel rods are fired into the soil at high velocity, typically up to lengths of 6 m where the soil conditions permit. Pull-out resistance is generated by direct soil to tendon interlock (frictional or cohesive).

Helical Anchors

Screw or helical anchors comprise a steel shaft (typically heavy wall tubing) with one or more fabricated or cast steel helical flights welded on. The flights are used for both for installation processes and to provide a bearing surface to generate the pull-out resistance. They are generally limited to soil applications but can have installation difficulties in dense gravelly soils. Helical anchors offer several benefits including:

- In some cases, they can be removed by unscrewing from the ground for demolition or re-use.
- Monitoring of torque during installation can provide (with site specific calibration) a measure of the pull-out resistance.
- Installation does not require soil to be self-supporting or a casing (as required in drilled and grouted options).
- Limited vibration and noise during installation.
- Anchors can be shorter than grouted anchors (useful if there are boundary constraints).

Deadman Anchors

Deadman anchors rely on gravity or passive resistance of the ground to generate load resistance. They are often formed as mass blocks (buried or on the ground surface) or beams/plates buried in the ground to which the free length of the tendon in mechanically locked. Examples include thrust blocks, buried slabs beneath tanks to resist uplift loads or beams set back from retaining walls to generate passive resistance.

Tension Ties

Where development geometry permits, the anchorage resistance can be generated by other geo-structural elements, such as might occur with back-to-back retaining walls linked by a common anchor tendon, usually with a waler.

5 DESIGN OF GROUND ANCHORS

5.1 GENERAL

Anchors should not be used unless their design and construction have been verified by testing, or by direct comparable experience[2], and have been shown to achieve the required performance and durability.

The design process therefore involves the development of a conceptual design through to detailed design that is subsequently validated and finalised through testing (see Section 6). Prior to field testing, the strength parameter values should therefore be treated as presumptive and evaluated to give confidence of performance outcomes, avoiding late redesign once field test results are available. The final design capacity of the anchor is the minimum value derived by project specific testing (considering load, deflection or creep criteria) or, if appropriate direct and explicit comparable local experience.

Most structural systems that utilise ground anchors are currently designed using the Load and Resistance Factor Design (LRFD) method by reference to either NZS1170 or the BM. The LRFD method employs both load factors and strength reduction factors (resistance factors) for each element to account for uncertainties. The LRFD method is adopted here to provide consistency with structural design and industry practice. In summary, under LRFD processes, the factored load resistance should exceed the factored load demands on the anchor components for all design load cases and for all failure mechanisms, expressed by the general terms:

$$R_d \ (= \Phi \times R_{uf}) > T_f \ (= \gamma \times T_{uf})$$

Where,
R_d = Design resistance
Φ = Strength reduction factor
R_{uf} = Unfactored resistance
T_f = Design load
T_{uf} = Unfactored load
γ = Load factor

Within geotechnical engineering practice it can be problematic to separate components of load from components of resistance to be able to apply appropriate load factors and resistance factors from NZS1170 or the BM. Therefore, in such situations holistic factors of safety may be appropriate. For geo-structural anchor designs, more generalised load and resistance factors are also presented here as an alternative to the NZS1170/BM approaches.

5.2 CAPACITY DESIGN

Capacity design principles are used in New Zealand in the seismic design of different elements of a structure. This approach recognises that seismic loads have a high degree of uncertainty, and the system needs to be designed to ensure a ductile performance. Ground anchors are critical elements and should be designed using capacity design principles to ensure acceptable performance in earthquakes or other overload situations.

Where the design seismic load is exceeded, the system should perform in a ductile manner, rather than experience brittle behaviour which leads to failure. For ground anchors, the following hierarchy of failure is adopted to ensure ductile performance:

a) A ductile tendon is selected to ensure that it has a minimum 6% strain post-yield without failure.
b) A lower strength reduction factor is adopted for the tendon to ensure that preferentially the tendon yields if the design load is exceeded in earthquake or other overloads.
c) An intermediate strength reduction factor is chosen for grout-bar bond failure, which is brittle, but has a greater certainty.
d) A higher strength reduction factor is adopted for a ground-grout bond failure or failure of the surrounding rock, as these mechanisms are brittle and have a higher degree of uncertainty due to the variability of natural materials.

[2] Comparable experience requires explicit and established information involving the same types of soil and rock and for which similar geotechnical behaviour is expected, the same construction techniques with similar structures, with particular emphasis on local experience.

The adopted ground anchor system should be checked to ensure that:

1) The above hierarchy of failure remains, that is, the tendon yields preferentially in the event of the load being exceeded.
2) The overall structural system is compatible with potential deformation of the anchor due to yielding of the tendon.

It is noted that the earthquake loading is applied over a series of short duration pulses (within an overall time interval that typically ranges from 10s of seconds to a few minutes). While the yield stress of the tendon may be temporarily exceeded it should be of limited effect (provided a rupture condition is not exceeded).

5.3 CONCEPTUAL DESIGN STAGE

In identifying anchor components, or anchor system options, a number of considerations need to be evaluated for development of a concept level design of the anchor system. At this stage the type and size of the anchor tendon should be evaluated as this may dictate the required hole diameter (and hence drilling methodology)[3].

5.3.1 PROJECT TEAM COLLABORATION

The requirements and performance expectations for the ground anchors should be understood and communicated between the geotechnical/structural designers, the constructors and the asset owners and requires a collaborative, best-for-project approach. The design and performance requirements that need to be coordinated and agreed between the structural and geotechnical engineer include:

- Soil-structure interaction and selection of appropriate modelling methodologies (to provide realistic estimates of the load demands and deflection performance).
- Anchor loads and capacity.
- Deformation characteristics (and impacts on utilities and other assets).
- Design working life and durability provisions.
- Inspection and maintenance expectations.

Design and construction team interaction must consider:

- Material certification.
- Fabrication, handling, storage and transport of system elements.
- Constructability and methodology.
- Impacts of construction on utilities and other assets.
- Quality control prior to and during installation.
- Post installation access and construction/stressing sequencing.
- Testing regime.

Design and client team interaction must consider performance requirements and expectations, typically including:

- Design working life and durability.
- Performance expectations (including post seismic).
- The whole of life costs (including maintenance) and offsets between levels of corrosion protection provided and levels of inspection and maintenance.
- Clear understanding of obligations for inspection and maintenance over the asset design working life.
- Post construction accessibility and the need for inspections, maintenance, re-stressing and replacement (if designed for).

5.3.2 SITE AND ENVIRONMENTAL CHARACTERISTICS

Key considerations, which would ideally include early contractor involvement in the selection of the anchor system, include:

- The site location (and remoteness), in particular the ability to safely deliver and handle long, factory anchor assemblies requiring rigid handling and lifting equipment.
- Accessibility to the anchor installation level (for construction and maintenance personnel, plant and equipment).
- Environmental conditions, atmospheric, exposure, groundwater and soil chemistry and permeability.
- Type of ground and suitable drilling methodologies (rock, soil, weak-strong, loose-dense, soft-stiff).
- Presence of voids in the ground and permeability (and potential for grout loss).
- Groundwater conditions (and flow).

5.3.3 GROUND CHARACTERISATION AND GEOTECHNICAL INVESTIGATION

Ground (and groundwater) characterisation and geotechnical investigations should be undertaken to develop a reliable ground model on which the anchor design can be developed through to testing. The scope of the site characterisation and investigation programme will be dependent on a number of considerations, which may include:

[3] The minimum hole diameter for permanent anchors is typically 125 mm but bond stress and corrosion protection requirements will often dictate a great diameter, typical construction diameters are 150 mm to 250 mm diameter. Smaller anchors installed by abseiling may use a smaller diameter such as 100 mm, to ensure practicality of drilling operations.

- Local ground conditions.
- Sensitivity of structures, slopes, infrastructure around the anchored area.
- Potential variability in ground and groundwater conditions.
- Site class (seismic).
- Sensitivity of the site to seismic shaking (including ground movements, rupture, strength loss associated with cyclic softening and liquefaction).
- Availability of existing anchor test data appropriate to the site-specific characteristics.

Intrusive investigations should be undertaken to support the development of a geological model. Model cross-sections should be developed to communicate the understanding of the stratigraphy and identify design, construction and performance risks. Laboratory testing maybe undertaken to characterise the geotechnical properties of the soils and rocks and support development of the design through the provision of presumptive design parameter values.

Strength parameters used for calculating the capacity of the anchors will generally, subject to extent and quality of available data and the sensitivity of asset performance, be chosen to represent 'moderately conservative' assessments of strength[4]. Stiffness parameters used for deflection calculations are difficult to predict and should therefore be generally given as a range of credible values that reflect the inherent model uncertainties.

Pre-construction ground anchor pull-out testing on 'sacrificial' anchors can be undertaken during the concept design and ground investigation phases of a project (subject to project programme, access, budget provisions and risk assessments) to inform the adopted detailed design parameter values and construction methodology or carried out during the early part of construction or enabling works.

5.4 DETAILED DESIGN

Depending on the type of structure and its location in New Zealand, either of the gravity load case or the earthquake load case may be more critical to the design of the anchor system. Therefore, sizing and layout of ground anchors should be evaluated for both the gravity load case and the earthquake load cases provided to the anchor designer.

5.4.1 DESIGN APPROACH

This section presents procedures that are commonly used to design a ground anchor, including:

- Derivation of anchor loads and expectations of deformation.
- Recommended load factors to be applied to the calculated anchor loads, which can vary based on the load case and analysis procedure.
- Failure mechanisms.
- Recommended strength reduction factors for the design of the anchor.
- Horizontal and vertical spacings of the anchor.
- Establishing the test load.

5.4.1.1 Design Process

Ground anchors are used in a wide range of applications such as slope stabilisation, retaining walls, foundations and to resist loads from a variety of structures. The effects of soil-structure interaction must be appropriately modelled in order to provide realistic estimates of the load demands and deflection performance. The process used for the design of ground anchors is outlined on Figure 5.1 (overleaf).

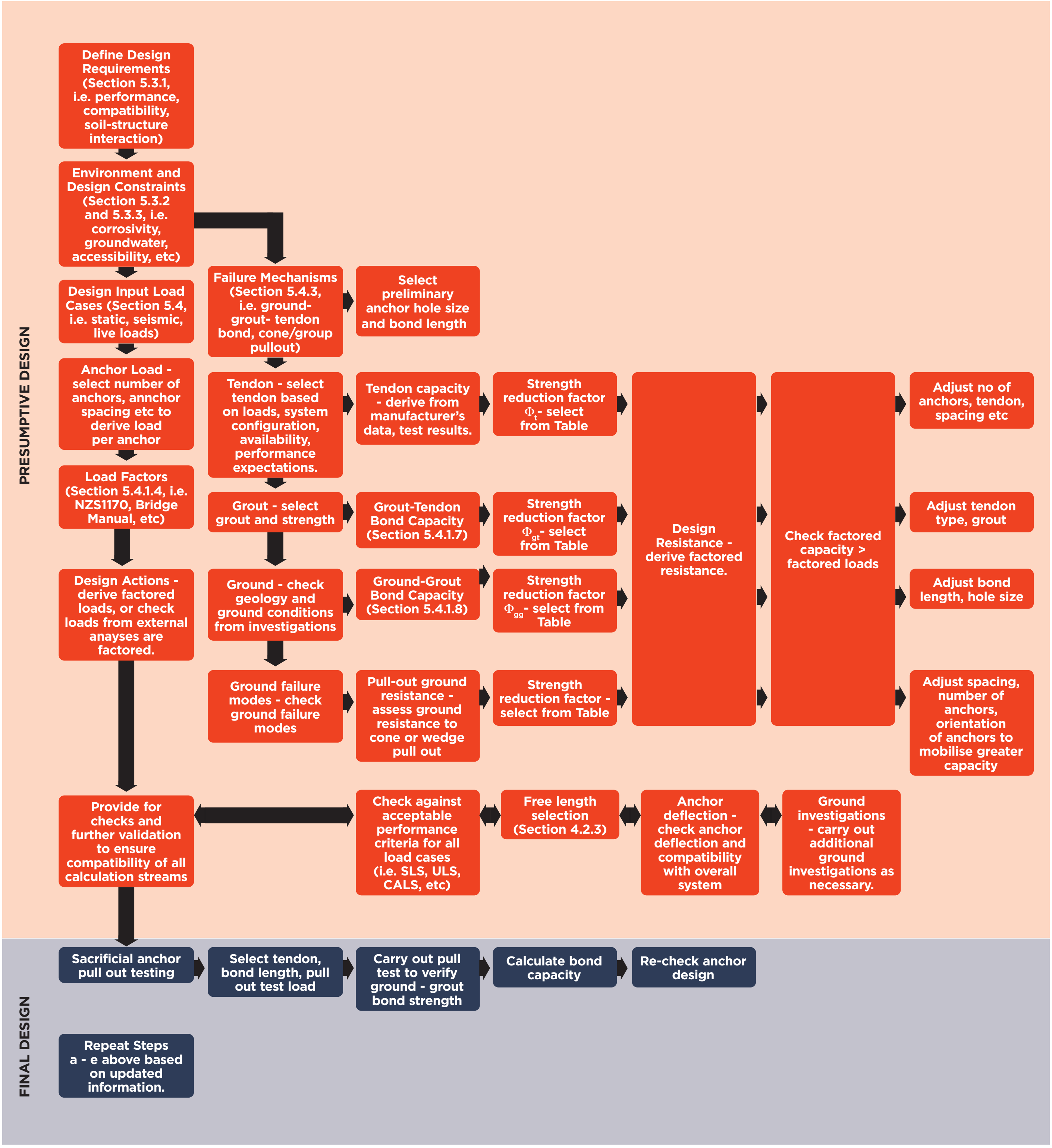
5.4.1.2 Derivation of Anchor Loads

The analyses used to derive the design loads may be derived from a range of modelling approaches. Methods of analysis typically fall into four broad categories:

- Limit equilibrium. This is the most common method of analyses used for the derivation of anchor loads for simple structures (including 'apparent' earth pressure models).
- Subgrade reaction or pseudo-finite element. This is used in some software used to analyse retaining walls or foundations.
- Numerical modelling (i.e., Finite Element or Finite Difference software such as Plaxis, FLAC, RS2, etc) with pseudo static or dynamic modelling (using scaled simulated earthquake ground motion records). With appropriate selection of the model parameter values and boundary conditions, numerical modelling can provide a more informed understanding of stiffness capability, deformations, structure demands and overall structure/anchor system behaviour.
- Structural models (which may rely, to lesser or greater extents, on soil-interaction parameters derived by one of the above approaches).
  In addition to tensile loads for which ground anchors are commonly designed, consideration should be also given to potential shear and bending loads from ground deformation such as when used to stabilise slope instability, including slope deformation under earthquake loads.

[4] Conservative best estimate or unlikely to be exceeded (but not worst physically possible)

FIGURE 5.1: Ground anchor design process flow chart



5.4.1.3 Deformation Expectations

Acceptable levels of deformation in different situations are key considerations in the selection and design of anchor systems to resist the applied loading. Deformation must be consistent with the application of the anchors and should not cause unacceptable loads or performance of the overall structural system.

The following are some considerations of deformation in the design of anchors:

- Under static conditions, the anchor tendon should remain elastic, and deformations should not affect performance of the structure supported.
- Under regular design earthquake level loading (SLS) the anchor tendon should remain elastic, and deformations must not affect performance of the structure.
- Under design earthquake level loading (ULS or DCLS), the anchor bar should remain elastic, permanent deformations are possible that may affect performance of the structure.
- Under extreme design earthquake levels (such as under larger than design level earthquakes, or CALS), the tendon may exceed its yield strength and deform plastically but must not rupture or lose capacity.
- When subject to ground deformation or impact loads (such as from rock fall), the tendon should remain elastic, and when subject to larger than design loads, the tendon should be ductile and may yield, but not fail in a brittle manner.

5.4.1.4 Load Factors

The loads derived (T_{uf}) from design applications should be factored using the standards appropriate for the design, for example the NZS1170 or the BM, to derive the factored design loads (T_f). These relevant standards would also provide the load combinations to be used for design. The loads should be derived for the relevant load cases such as static, SLS1, SLS2, ULS, DCLS or CALS, which will depend on the design standard used for the specific application.

The choice of load factors should take due consideration of the uncertainties in the design loads and analyses methods used to derive the loads, as well as consequence of failure. Where anchor loads are not derived by reference to either the BM or NZS1170, Table 5-1 below provides the recommended load factors to be applied to derive the factored design anchor load (T_f).

These load factors should not be confused with factors of safety from slope stability analyses used where anchors are used in such situations, and this is not covered in this document.

TABLE 5-1: Design load factors

LOAD CASE	LOAD FACTOR (γ)
Static – Earth Pressures	1.5
Static – Max Surcharge/ Live Load	1.35
Static – High Groundwater	1.35
Static – Temporary, unplanned over-excavation	1.35
Seismic – SLS/ULS/DCLS	1.1
Seismic – MCE/CALS	1.0

5.4.1.5 Failure Mechanisms for Ground Anchors

Failure mechanisms that must be considered in the development of the design of ground anchors include:

- Tendon strength (resistance[5]).
- Grout to tendon bond strength (resistance).
- Ground to grout bond strength (resistance).
- Ground failure (resistance) due to an applied tendon load.
- System and global failures not associated with tendon loads (for example, failures around anchored walls, structural connectivity, drainage systems) are not covered in this document).

Whilst this module provides design guidelines for individual ground anchors, due consideration is also required as to redundancy of the overall anchor system, in particular failure of one anchor should not lead to progressive or catastrophic failure of the whole system.

5.4.1.6 Tendon Strength (Resistance)

The tendon, and any coupling system, should be selected based on considerations of structural capacity and ductility.

The tendon may fail in tension due to the applied load exceeding the capacity of the tendons. Tendons typically have two load capacities:

(i) Yield load (F_y), at which the tendon begins to yield with permanent deformation of the tendon.
(ii) Ultimate Tensile Strength (F_{UTS}), at which the tendon fails, or loses strength, in tension.

[5] Note: the terms 'strength' and 'resistance' are often used interchangeably, reflecting diversity in the published terminology

Coupling systems used to connect lengths of tendons should have capacities (F_y and F_{UTS}) that exceed the capacity of the tendons. The number of couplers should be minimised, taking into consideration the space available for construction that may limit the length of tendons (where bars are used). Couplers should preferentially be used in the bond length, rather than the free length.

Seismic design requires the selection of tendons and couplers that are ductile and have substantial post-yield capacity, at least 6% to 10% strain capability without failure. A higher ductility (% strain) steel would be selected where post-event (eg earthquake) performance is critical. Where brittle tendons such as GRP bars or couplers are selected, then there should be a suitably high margin against brittle failure under extreme earthquake loads. This latter consideration would be partially satisfied by reduction of the design strengths to limit creep with GRP bars, which is not a consideration for short term seismic loading.

The anchor tendon must be capable of transmitting the anchor load to the anchor bond zone in an elastic manner for all limit states except for extreme seismic cases (such as CALS or MCE load cases) where ductile deformation, avoiding rupture, is acceptable. The tendon must also be capable of resisting the maximum anchor test load.

Where tendon resistances are not derived by reference to either the BM or NZS1170, Table 5-2 below provides the recommended strength reduction factors (Φ_t) to be applied to the manufacturer's published tendon capacity (resistance) to derive the tendon design strength, $R_{d;t}$

5.4.1.7 Tendon-Grout Bond Strength (Resistance)

In ground anchors, the load transfer mechanism between the tendon and the grout is dependent on the relative elastic moduli of the grout and tendon. Typically, the tendon-grout bond strength is higher than the ground-grout bond strength and is not a controlling factor in design.

The bond between a steel tendon and the surrounding grout comprises components of mechanical interlock, friction and adhesion and is not uniformly mobilised along the bond length. The relative contributions of these elements to the resistance of the grout-tendon interface are governed by the material selection and tendon detailing. In addition, the bond resistance is not proportional to the compressive strength of the cured grout.

Therefore, strengths and minimum tendon-grout bond lengths, based on compatible and published pull out testing data, should be used in design wherever possible.

For multistrand anchors the total perimeter of all the individual strands should be used for the tendon-grout bond strength (which assumes strands are separated and splayed through the bond length).

TABLE 5-2: Anchor tendon design strength reduction factors

TENDON TYPE	STRENGTH REDUCTION FACTOR (Φ_T)	APPLICATION
Wire steel strand or low[6] ductility steel bars	0.7	Strength reduction factor applied to the Ultimate Tensile Strength F_{UTS} (**not** yield strength), recognising the limited ductility of these elements.
Ductile Grade 500E or 1050 Steel Bar or high strength steel bar	0.8	Strength reduction factor applied to the Yield Tensile Strength, Fy (**not** the ultimate tensile strength), recognizing the ductility of these materials
GRP Bar	0.4[7]	Strength reduction factor applied to the Ultimate Tensile Strength F_{UTS} (**not** yield strength), recognizing the limited ductility of these elements.

6 Less than 6% strain beyond yield strength

7 This is a moderately conservative default value; higher strength reduction factors may be used in line with manufacturer's recommendations on creep limited capacity of GRP bars.

Typically grout with a minimum compressive design strength of 40 MPa is adopted and a minimum attained strength of 30 MPa is assumed prior to stressing. On this basis, where published data is not available and for simplicity, tentative maximum ultimate bond design strengths (assumed to be uniform over the tendon bond length) are as follows:

a) 1.0 MPa for clean, plain wire or a plain bar.
b) 1.5 MPa for clean, crimped wire.
c) 2.0 MPa for a clean strand or a deformed bar.
d) 3.0 MPa for locally noded strands.
e) 5.0 MPa for clean thread bar with coarse pitch thread form (d/2, d/3) bar.

The recommended strength reduction factor to be used to derive the grout-tendon design resistance ($R_{d;gt}$) is $\Phi = 0.5$.

5.4.1.8 Ground-Grout Bond Strength (Resistance)

The ground-grout bond strength has the most uncertainty because it depends on:

a) The ground conditions at the site and its variability.
b) Groundwater conditions.
c) Presence of voids/rock defects.
d) Construction methods including drilling technique, tools and operator skill
e) The different elastic characteristics of the tendon, the grout and the surrounding ground which can collectively contribute to progressive debonding along the grout-ground interface.

The ground-grout bond therefore requires careful consideration during design and construction. Typically, the ground-grout bond capacity in soil and rock is selected using the following process:

- Site investigations to characterise the ground and groundwater conditions in soil and rock.
- Selection of preliminary ground-grout bond capacities based on prior experience.
- Design of ground anchors using preliminary values of ground-grout bond capacity and check sensitivity of the design for potential variation/uncertainty.
- Specify ground anchor testing required during construction.
- Sacrificial anchor tests early in the construction period (or prior to construction during enabling works) to determine bond capacities. The ground-grout bond is tested to failure to determine the ground-ground bond strength.
- Review of the sacrificial anchor test results to assess the ground-grout bond capacities and variation across the site, and review and adjust the anchor design and construction techniques as appropriate.
- The designer should assess the consistency and ability of the installed anchor to resist the design loading without excessive deformation. Key characteristics to consider include:

a) Failure load (anchor bond failure, or load at which anchor displacement starts to become excessive.
b) Bond capacity (anchor failure load ÷ surface area of bond length).
c) Load – displacement characteristics (acceptability of displacement to mobilise required factored design load).
d) Creep during sustained load.

The following guidelines should be considered when evaluating the design bond length:

a) The minimum bond length should be 3 m to allow for uncertainties in design, load transfer mechanisms and construction.
b) Generally, for grouted tendons, the bond length should be limited to a maximum of 10 m.

When calculating the tendon-grout bond resistance it is common, for simplicity, to assume uniform stress distribution over the area of the grout to soil/rock interface i.e. the nominal surface area of the soil-grout bond length is applied to the design resistance (R_d), based on the nominal drilled diameter of the hole (unless the anchor bond length is reamed, belled, grooved boreholes or pressure grouted). However, load transfer is not uniform along the bond length and the ground-grout bond strength is progressively mobilised along the bonded length, starting from the top of the bond length. Progressive debonding may occur in strain sensitive or brittle soils and rocks, and/or if the relative anchor/ground stiffnesses are too large. Therefore, the ground-grout bond efficiency reduces with increasing fixed length.

Ideally the tendon-grout bond strengths that are relied upon for production anchors should therefore be determined from pull out tests on fixed anchor test lengths are compatible with the final production anchors. A refined methodology, accounting for progressive debonding, can be considered by application of a bond 'efficiency' to the design bond strength, as follows:

For anchors in Clays, silts, sandy clays

$$f_{eff} = 1.6\ L_{fixed}^{-0.57}$$

For Anchors in fine sands

$$f_{eff} = 0.91\ L_{fixed} \tan(\phi')$$

For anchors in rock the designer needs to consider progressive debonding where anchor lengths exceed the 10m limit, particularly in highly fractured and weathered rock.

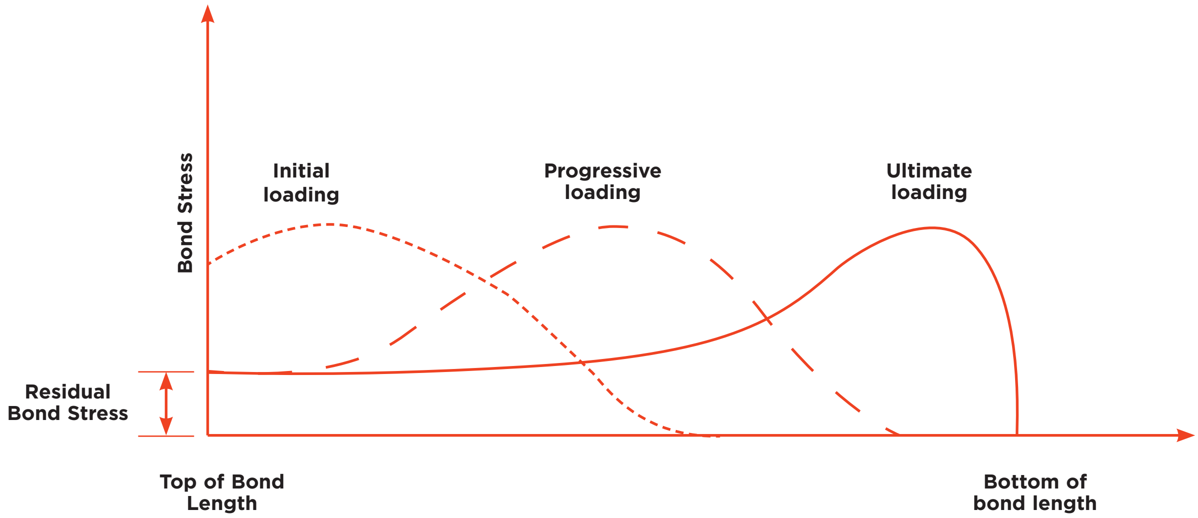


FIGURE 5.2: Mobilisation of bond stress for a tension anchor

5.4.1.9 Options to Enhance Ground-Grout Bond Capacity

The ground-grout bond capacity may need to be enhanced to achieve acceptable, practical and economical anchor diameter and length, and acceptable load-displacement characteristics. This enhancement may require the consideration of different techniques to enhance the bond capacity. These techniques may include:

- Drilling technique – vary the drilling technique and preparation of the anchor hole.
- Grooving the anchor hole.
- Pressure-grouting of the anchors.
- Preliminary grouting followed by post-grouting under pressure using a tube a manchette (TAM).

5.4.1.10 Effects of Drilling Technique on Ground-Grout Bond Strength

Access and ground conditions will influence the selection of drilling rigs for most anchoring projects and, to an extent, this will dictate the drilling technique selected. The drilling technique selected can have a significant impact on the bond capacity achieved. The designer should understand the effect of the combination of ground conditions and drilling techniques on the bond capacity and specify and select the drilling technique in collaboration with the contractor. There are three common drilling techniques available:

- Rotary wash drilling with air and water.
- Rotary percussion drilling (down-the-hole hammer).
- Auger drilling.

The addition of casing where ground is not self-supporting is also common in combination with each of these techniques. Further commentary on the effect of construction methods is presented in Section 7.1.2.

Typical ground-grout bond capacities are provided in Appendix D. These capacities should be used with caution and only for preliminary design of anchors and need to be confirmed with sacrificial anchor tests to assess bond capacity. Note that in soils the bond capacity could be limited by deformation and creep, rather than strength. Therefore, the selection of presumptive values from Appendix D should generally adopt moderately conservative estimates from the ranges provided, modified where appropriate based on experience and judgement of the actual ground characteristics and the effects of drilling method to be adopted.

Preliminary ground-grout bond capacities for cohesionless soils can be estimated from the soil strength and overburden pressure. However, these also needs to be verified with prior knowledge of bond capacities that can be achieved and followed up with sacrificial anchor tests.

5.4.1.11 Ground-Grout Bond Design Strength Reduction Factors

Ground to grout bond strengths are sensitive to broad ranges of factors that should ideally be accounted for in the selection of ground-grout strength reduction factors. Where no detailed assessment of these sensitivities is undertaken, the recommended default strength reduction factors (Φ_d) are as provided in Table 5-3.

Table 5-3: Recommended default ground-grout design strength reduction factors

Load Case	Φ_d	Comments
Static, Live Load, High Groundwater, Seismic SLS/ULS	0.5	Consider lower Φ_d in soils to limit deformation and creep.
Seismic – MCE/ CALS	0.75	Value reflects extremity of these load cases

The following optional guidelines are presented to provide for refined evaluation of the ground-grout strength reduction factor from the default values provided in Table 5-3, accounting for weighted sensitivity of the design factors that influence ground-grout strengths.

$$\Phi = \Phi_d + (0.85 - \Phi_d) * \Sigma (w_i . K)$$

Where w_i and K are the weighting and risk factors respectively, derived from Table 5-4. The strength reduction factors derived from this table should be revisited and design updated during the design process as more data becomes available.

The strength reduction factor derived from the above equation should not exceed a value of 0.85, but also noting that where the design is undertaken in accordance with the BM the value should not exceed 0.75 for CALS.

Table 5-4: Risk and Weighting factors for detailed assessment of ground-grout bond factors

Risk Factor		Weighting Factor (w_i)	Risk Factor, K, for typical description of circumstances		
			Very Low Risk K=1	Moderate Risk K=0.5	High Risk K=0
Ground Model	Ground Model Certainty	0.3	Comprehensive drilling investigation covering all acnchoring locations and to levels consistent with proposed anchoring horizons with horizontal strata, well defined soil, rock and groundwater characteristics	A moderate number of boreholes covering a representative number of anchor locations and horizons. Some variability over site, but without abrupt changes in stratigraphy	Very limited investigations. Highly variable profiles, abrupt changes in stratigraphy (such as steeply dipping rock levels or faults present on site; or combination of these)
Design	Basis of determination of Design Parameter Values	0.4	Based upon local and comparable anchor tests. Detailed information on soil/rock strengths (through insitu and/or laboratory testing) and good quality data on rock characterisation (including nature of joints, fissures, bedding and faulting)	Well-established and theoretically based method using moderately conservative values of derived parameter values based on representative records of ground characteristics, limited testing and moderate quality of borehole logging	Based on empirical, non-site specific data correlations Poor quality records and no laboratory test data
Installation	Contractors Experience	0.3	Contracting team have installed and tested anchors within the same geological units with similar characteristics and with similar plant and materials	Contracting team have installed and tested anchors within similar geological units	No ground anchor installation and testing experience within geological unit or with methodology to be adopted or contractor not yet selected

5.4.2 DEFORMATION OF ANCHORS AND PRESTRESSED ANCHORS

Passive anchors require some deformation to mobilise the ground-grout bond strength and anchor bars can elongate during loading through the unbonded zone. This could be beneficial in seismic cases, for example in retaining walls, where allowance for deformation reduces the earth pressure loads on the wall.

Deformation of the system should be considered during design and where predicted deformations are considered too high for the system, prestressing the anchors can be considered to reduce deformations.

The prestressing process tensions the anchor to a desired load and locks off the load in the anchor head during construction. The prestress load in the anchor will gradually reduce over 5-20 years (depending on the ground-grout bond type) and allowance for restressing the anchors during maintenance of the system should be scheduled over the life of the anchor system. If the anchors are not restressed, the system will gradually relax, and deformation will likely occur over time.

Prestressing anchors on a retaining wall can induce higher structural forces in wall cantilever piles and the effects of prestressing on other parts of the anchored system should be considered during design.

5.4.3 FACTORS LIMITING MOBILISED ANCHOR STRENGTHS

A range of factors can adversely influence the capacity of both individual anchors and anchor systems and these should be evaluated during design.

The effects of liquefaction are beyond the scope of this module, but the designer should ensure that anchor does not rely on resistance of soils that may be prone to the effects of liquefaction or, more generally, within soils where cyclic softening can occur.

The anchor design should be checked against failure due to:

a) Group or cone pull-out failure
b) The presence of unfavourable bedding planes/ defects which promote adverse failure mechanisms through planes of weakness

Alternative guidance from BS8081 and FHWA standards should be referred to in this instance. Examples of a cone pull-out failure mechanism is illustrated in Figure 5.3 below:

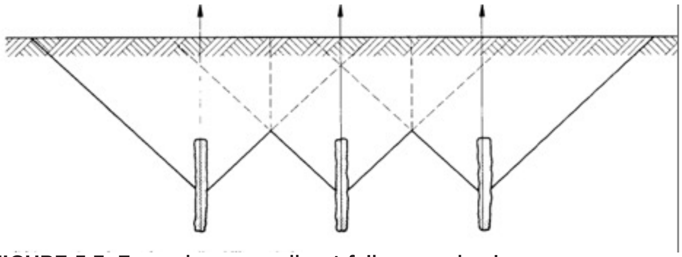


FIGURE 5.3: Example cone pull-out failure mechanism

5.5 ANCHOR HEAD DETAIL

Anchor heads are critical elements of a ground anchor system, where the load on the structure is transferred from the structural member (retaining wall or foundation) or ground (in the case of a slope). Critical anchor head elements that require design are the nut on the threaded anchor tendon (or strand anchor tendons), a dome plate (or wedge plate) and the anchor plate. Usually, proprietary nuts are provided with the tendon, and should be checked to ensure they are rated for the loads applied. The dome nut and plate are designed to allow some rotation between the alignment of the anchor tendon and the anchor plate.

The anchor plate should be designed to have sufficient thickness to carry the shear loads from the anchor nut- dome plate that bears on it as well as have adequate size to transfer the load to or from the structural member (or ground) as well as the test loads. The punching shear capacity of the plate and the structural member or bearing capacity of the rock or ground will be important mechanisms to be checked. Larger or smaller anchor head – plate configurations can be adopted where the thickness or capacity of the structural member is limited, such as in applications in the strengthening of existing structures.

Anchor plate dimensions shall be carefully considered where bearing directly on timber poles to avoid anchor pull through on the pile.

Moments in the anchor head should be considered and avoided, minimised or checked for.

The anchor head design should include consideration of how the anchor head is incorporated into the overall structural or ground support system and its protection. This will vary depending on the system, the need for access for maintenance, access constraints, and mechanical and corrosion protection (see more in Section 6).

Common head configurations include (see Appendix E for diagrams or photographs of examples):

a) Anchor plate bearing on the surface of concrete or steel structural members or timber posts (timber pile walls), or rock, ensuring compatibility to avoid bi-metallic corrosion or protection to avoid deterioration due to timber treatment chemicals.
b) Protection of anchor head with petrolatum compound and tape (see more in Section 6)
c) Encapsulation of protruding anchor tendon and nut with a metal or plastic cap (the cap may be filled with petrolatum compound if anchor requires stressing or with grout if passive anchor with no requirement for future stressing).
d) Encapsulation of the anchor head within a reinforced concrete member (where no future access for stressing is required).
e) Encapsulation within an anchor head within a concrete block embedded in the ground.

6 CORROSION PROTECTION

6.1 GENERAL

Protecting the components of the anchor system against the detrimental effects of corrosion is essential to assure adequate long-term durability of the system. The selection of the corrosion barrier system(s) must reflect the intended design working life (temporary or permanent applications), the environment (such as coastal exposure, ground and groundwater aggressivity, stray currents), the consequences of failure of the anchored system, and the additional cost of providing a higher level of protection.

The corrosion protection system must comprise components that collectively provide an unbroken barrier for every part of the anchor system and the transitions between them. The structural load transfer pathway for an anchor is linear with no redundancy within a single anchor installation. Therefore, the element within the overall anchor system, including transitional elements, with the least protection defines the class of protection provided.

Cathodic protection of anchors can be considered but is generally fraught with technical and cost considerations and is a specialist subject area beyond the scope of this guideline.

It is noted that different terminologies for corrosion protection classes are used across different international standards to categorise the level of corrosion protection. The different protection classes and terminologies are summarized in Table 6-1 below.

This document provides guidance on corrosion protection on a level adequate for many standard applications. For special applications, greater detail or background on corrosion protection systems following documents should be considered:

- FHWA A-IF-99-015 Ground Anchors and Anchored systems
- BS EN 1537:2000 Execution of special geotechnical work – Ground Anchors
- BS 8081:2015 – Code of Practice for Grouted Anchorages
- SNZ TS 3404:2018 - Durability requirements for steel structures and components

Further details and descriptions for each of these classes is provided in the following sections and the reader should refer to Figure 6.1 for an informative guide to a selection process adopted within this guideline.

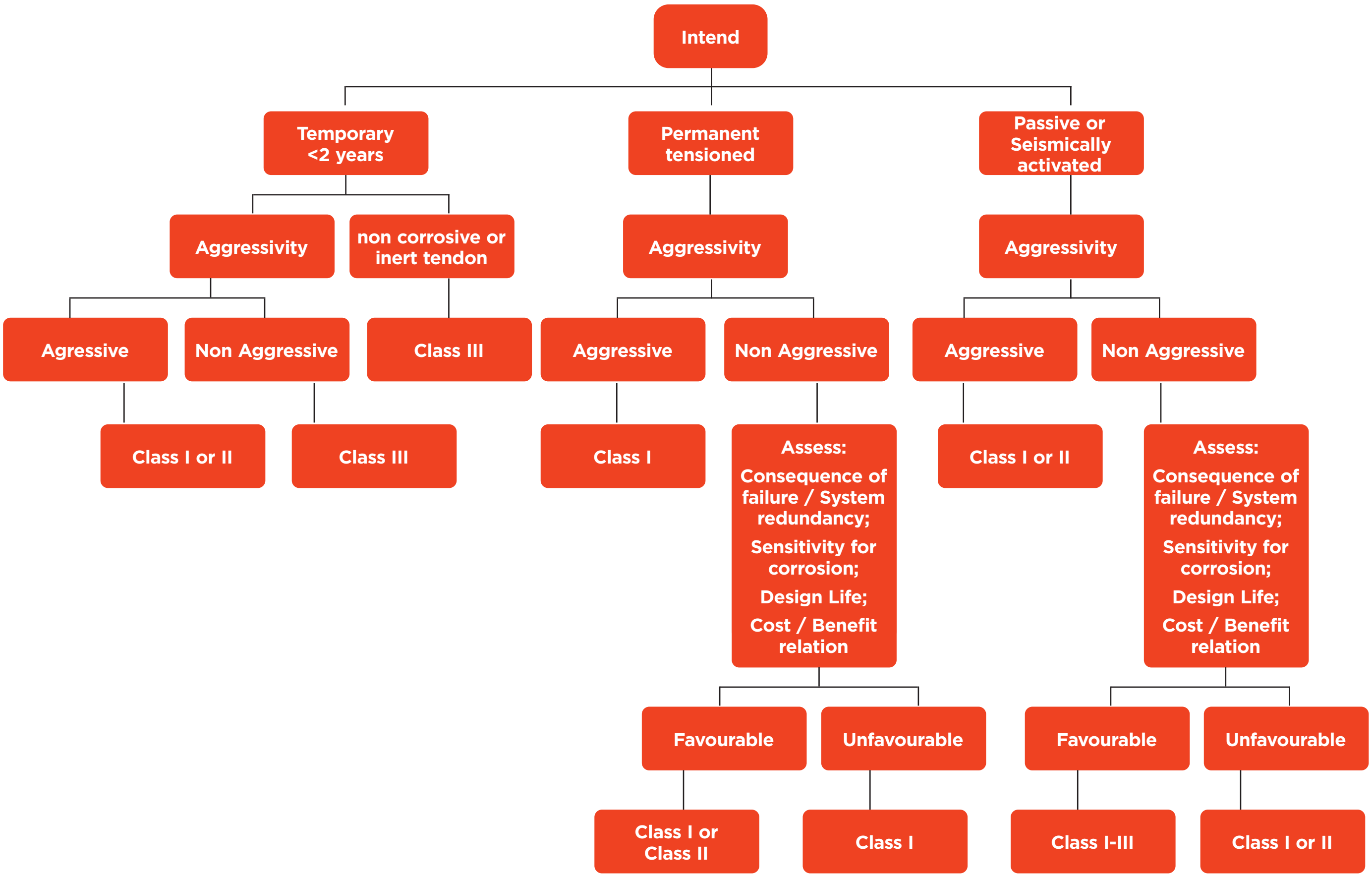
The flow chart presented in Figure 6.1 below presents a pathway to selection of a suitable corrosion protection system. Alternative decision pathways as well as alternative corrosion protection systems can be considered provided these are applied and implemented in accordance with reference documents from which they are drawn. If no testing or assessment has been performed, the ground/groundwater should be assumed to be aggressive.

TABLE 6-1: Anchor protection class descriptions

CORROSION PROTECTION CLASS	SUB-CLASS	OUTLINE DESCRIPTION (NOTE: DIFFERENT DETAILS WILL APPLY TO THE INDIVIDUAL ZONES OF THE ANCHOR SYSTEM)	GUIDE TO TYPICAL APPLICATIONS	CLOSEST EQUIVALENT[1] DETAIL IN OTHER STANDARDS (A) BS8081 (B) BM (C) FHWA
Class I **(Encapsulated Tendon)**	S (Special circumstances)	Multiple layers of corrosion protection are provided	Extremely high risk/ aggressive environments or where economic considerations support investment in highest levels of durability	(a) 'Double Corrosion protection' (b) 'A higher Class of Protection' as provided in the Footnote to Table 6.5 in BM (c) No equivalent level of corrosion protection in FHWA.
	D (Default)	Protection by encapsulation of a tendon assembly inside an inert and impermeable plastic sheath.	Default for Permanent Anchor applications unless considerations support adoption of alternate levels of protection	(a) 'Single Corrosion protection' (b) Class I protection (c) Class I protection.
Class II **(Protected Tendon)**	N/A	Corrosion protection is provided by controlled grouting operations and, where used, tendon coatings	Permanent Anchors where ground and groundwater conditions are favourable. Temporary anchors in low-risk environments. Passive and seismically activated anchors in non-aggressive environments with low permeability ground and low risk applications.	(a) 'Unprotected Ground Anchor' (b) Class II protection (c) Class II protection.
Class III **(No-protection)**	N/A	No explicit protection measures other than may be afforded by the default tendon to soil/rock interface conditions	Temporary anchors only and only in non-aggressive environments with low permeability ground.	(a) 'Unprotected Ground Anchor' (b) Not referenced in BM (c) 'No protection'.

[1] A key difference between BS8081 and the FHWA is what the standards consider a level of 'protection'.
- Cement grout is not considered an acceptable corrosion barrier within BS8081
- Under BS8081 double corrosion refers to a sheath that provides protection during handling and installation to the primary corrosion protection layer

FIGURE 6.1 - Minimum Anchor Classes (note that a higher class of protection may be necessary due to other factors)



There are ranges of other considerations that may influence the level of corrosion protection adopted for an anchor system. A matrix of some other considerations to inform the final selection of the overall system is presented in Table 6-2 (other system/ development or location specific considerations may also need to be included). Where information is absent unfavourable conditions should be chosen.

TABLE 6-2: Summary of favourable and unfavourable conditions for ground anchors

DESIGN CONSIDERATION	FAVOURABLE	UNFAVOURABLE
Susceptibility	Solid bars, hollow bars, ductile steel.	multi strand, mild steel
Exposure	Fully encapsulated head, impermeable or low void ground (e.g. clay, massive rock). Benign environmental and atmospheric exposure.	Exposed head, permeable (high void content) ground (gravel, fractured rock or sand) with possible oxygen, and surface water exchange particularly within the first 3 m of total anchor length. Aggressive atmospheric conditions.
Redundancy	Failure of individual or few anchors due to corrosion would still provide satisfactory performance of the system.	Failure of individual anchors due to corrosion is unacceptable.
Design working life	Limited design working life.	Opportunity for design working life to be extended.
Load Condition	Passive or event activated – temporary loaded.	Permanently stressed or pre- stressed.
Control	Rigorous monitoring and inspection regime.	Anchor elements not accessible or visible.

Possible and common corrosion protection measures in accordance with the corrosion protection (CP) classes are shown in Table 6-3 below. Note that other means of protection are possible and can be in accordance with CP classes but will require a specific design and verification in terms of efficiency and design working life.

Where propriety systems are used these need to be installed complete and in accordance to the suppliers specification and guidance. E.g. where petrolatum grease systems are part of the corrosion protection regime, pre-treatment (e.g clean, dry and pre-grease), overlap requirements (usually minimum 50%) and other specifications (surface protection) shall be considered.

TABLE 6-3 Summary of Corrosion Protection for Anchor System Elements (modified after FHWA)

CORROSION PROTECTION CLASS	CORROSION PROVISION TO SYSTEM COMPONENT		
	ANCHOR HEAD[*5]	TENDON	BOND LENGTH
I(S) & (D) **(Encapsulated Tendon)**	1. Trumpet 2. Cover or encapsulation	1. Encapsulate tendons composed of individual grease filled extruded strand sheets with a common smooth sheet[*1] 2. Encapsulate tendons composed of individual grease filled strand sheets with grout filled smooth sheet[*1] 3. Use smooth bond breaker over grout filled bar sheath[*1]	1. Grout filled encapsulation[*1] 2. Fusion bonded or factory sprayed epoxy[*1*6] 3. Galvanizing[*3*6]
II **(Protected Tendon)**	1. Trumpet 2. Cover or encapsulation	1. Grease filled sheath[*1] 2. Heat shrink sleeve[*1] 3. Galvanizing[*2*6] 4. Fusion bonded or factory sprayed epoxy[*1*6]	Grout [*4]
III **(Unprotected)**	None[*3]	1. None [*3] 2. Galvanizing [*3*6] 3. Grout [*3]	Grout[*4] or none for mechanical anchors[*3]

[*1] – the installation process or the selection of the protective measure must ensure that the installed protection is intact and effective over the design working life. Proof may be required e.g. by conductivity testing. Powder coated bars are not acceptable.

[*2] – Galvanising will require specification with respect to the maximum time of efficiency of the protection and is limited in all cases to a maximum of 25 years. HD600 is the generally accepted grade of galvanisation for most cases, refer to NZS2313 for more guidance. HD900 has practical limitations.

[*3] – the minimum desired design working life e.g. for temporary anchors will still need to be met and verification is required in the design.

[*4] – a minimum grout cover of 25mm and a minimum 125mm hole diameter (for permanent anchors) is required and should be provided by the correct use of centralisers.

[*5] – Anchor head protection measures may be reduced where the anchor head is not part the load path - e.g. fully grouted rock bolts. Appropriate protection to the bonded bar end is still required.

[*6] – All galvanizing and coating systems shall be assessed by the Engineer with respect to appropriate and proven long-term reliability, QA processes, influence of workmanship, applicators experience, compatibility and robustness. Recommendations in SNZ TS 3404:2018 should be considered.

Examples of Corrosion Protection for Anchor System Elements (modified after FHWA) can be found in Appendix E.

6.2 ANCHOR ELEMENTS AND THEIR PROTECTION

6.2.1 GENERAL

Complexity, exposure and sensitivity govern how much effort, detail and care need to be given to the various design elements. Where generally inert materials are used (e.g. GRP), then material and system selection should consider the design working life and durability requirements recommended by the manufacturers and from the results of independent performance certification.

6.2.2 TENDONS

Whilst some elements within structural design can permit thicker, 'sacrificial' structural section sizes as a means of addressing strength loss due to corrosion this approach is generally not recommended for tendon design because it is not possible to identify such deterioration, there is no redundancy in load paths and, other than replacement, there are no maintenance options. If the use of sacrificial steel to provide corrosion resistance is considered, then all of the following conditions should be satisfied:

- There are no adverse aggressive or environmental conditions.
- The anchors are event activated (e.g. earthquake) and not permanently stressed.
- The steel used has a high resistance against pitting and embrittlement.
- The overall anchors system has redundancy for failure of individual elements.
- The design working life of the anchor is robustly evaluated, maintenance and replacement provisions are clearly communicated to the asset owners and maintenance teams.
- For solid and hollow bar tendons, corrosion protection systems can include galvanising and epoxy coated systems.
- Galvanised coatings have some abrasion resistance, but it needs to be recognised that anchor lifespan is also dependent on the levels of aggressivity in the ground.
- Epoxy coated systems should not be used in self-drill application due to the poor abrasion resistance of the coating. The coating can also be damaged when the bar is clamped for release from the drill head.
- In all cases care must be exercised in the transport, storage and placement of these materials to avoid damage to the coatings (small areas of damage to galvanising, no greater than 3-5mm in size, normally have little effect on the life of the coating due to the cathodic protection afforded to the parent steel).

For temporary anchors (working life up to 2 years) a cement grout cover of at least 25mm thickness is considered to be appropriate to provide some limited protection to the tendon. Within the free length, it is imperative that air, water and corrosion promoting agents cannot reach the strand and this is normally achieved by the use of individually greased and sheathed strands. A film of rust on a tendon may not necessarily be harmful but does require assessment and, in particular, any evidence of pitting[8] would be unacceptable

Within the unbonded length of a permanent anchor, the following requirements should be fulfilled as a minimum:

- Sheaths used to protect the unbonded length should extend into the trumpet but not so far to come into contact with either the bearing plate or the anchor head during stressing.
- Sheaths should be filled either with a corrosion-inhibiting compound or grout in a manner that does not leave voids.
- Strands should be individually coated with a corrosion-inhibiting compound, without leaving voids between wires. This also is applicable to bars with rough surfaces such as thread.
- For Class I protection of strand tendons, a common smooth sheath encapsulation should be used over tendons composed of extruded grease filled strand sheaths, or a grout filled common smooth sheath encapsulation should be used over tendons composed of individual grease filled strand sheaths.
- Where corrugated pipe is used as a sheath, a bond breaker must be present. A bond breaker is a smooth sheath used in the unbonded length that allows the prestressing steel to freely elongate during testing and stressing, and to remain unbonded to the surrounding grout after lock-off.
- For Class I protection of bar tendons, the couplers must be protected using either a corrosion proof compound or wax impregnated cloth tape and a smooth plastic tube.

Corrosion related tendon failure in the bonded length is very rare where full grout encapsulation is provided. In rock, where groundwater seepage around the tendon may be significant, drill hole waterproofing may be necessary to ensure that the grout remains in place. A watertightness test (see section 7.4 of PTI,1996) can be performed to determine the need for special waterproofing measures. If waterproofing is indicated, consolidation grout is commonly placed in the hole and redrilled approximately 18 hours after placement.

[8] Pitting is typically described a condition where the loss of material in the surface of the materials has a depth/width ratio of 1 or greater

In some cases, additional levels of protection are required (Class 1(S)) and this is achieved by providing a secondary duct which acts to protect the primary corrosion protection layer during handling and placement of the tendon. Over the bond length the sheath is typically corrugated. Over the de-bonded length, the secondary sheath should be smooth, but if a corrugated sheath is used then it should be fitted with a bond-breaker. It must be noted that provision of two concentric layers of ducting has a significant cost implication to the project as a much larger drill hole diameter is required. Unless specific measures are taken it is possible that the added difficulties and constraints for handling, placement and grouting can compromise the intent of the double corrosion protection provisions. In these circumstances it is essential that the site is suitable for such installations and that contractor has the skills, experience, and capability to successfully install the assembly.

6.2.3 ANCHOR HEAD

For most anchors the components within the first 2-3m of the anchor head are at the greatest risk of corrosion. Reasons for this include the complexity of the interaction of several different components and their connection and proximity to air/oxygen. Greatest care needs to be given to the selection, design, and installation of corrosion protection measures within this zone.

Physical encapsulation can protect the anchor head and the exposed stressing steel from corrosion and physical damage. This can be in the form of a fabricated steel or plastic cap. The caps should be filled with grout, or a corrosion inhibiting compound (e.g. an appropriate petrolatum grease) in the case of re-stressable anchors. Concrete encasement is also an effective way to protect the anchor heads.

For temporary anchors, wrapping the exposed anchor head and prestressing steel with a petrolatum/tape system may provide adequate protection. However, these systems shall be applied as per manufacturer's specification, considering pre- treatment and weathering protection as well as overlapping requirements. For removable strand anchors, PVC tubing is often also placed over the strand tails to provide additional protection.

The underside of the bearing plate is typically also an area of high corrosion risk as at this point both oxygen and moisture are present, which when combined will promote corrosion if the tendon is unprotected.

In the case of permanent anchors, a steel trumpet welded to the back of the steel bearing plate provides protection to the prestressing steel in the transition to the free length. The trumpet needs to be long enough to overlap the free length corrosion protection by at least 100mm and should be filled with grout (after stressing and lock-off) unless re-stressing is required. For re-stressable anchors, the trumpet is filled with a corrosion inhibiting compound (e.g. petrolatum based grease) to protect the steel components in the anchorage. Cement grout should not be allowed to bleed through strand anchor heads as this affects the performance of the wedge grips.

The following requirements and detailing should also be fulfilled as a minimum.

- Ensure no grout can escape into the unbonded length after stressing, re-stressing or lock off.
- Provide a seal to retain grout in the trumpet.
- Provide for expansive admixtures or multiple grout stages, if required.
- Ensure old grout surfaces are clean prior to re grouting.
- For restressable anchors, the trumpet should be filled with a corrosion-inhibiting compound and a permanent seal should be provided at the bottom of the trumpet. For corrosion-inhibitor filled trumpets, care should be taken to ensure that seals will not leak.
- Bearing plates require adequate corrosion protection systems, such as protective coatings which should be compatible to the other protective materials used.
- Cast in place concrete encasement is also possible with a minimum of 50mm concrete coverage and reliable (design working life compatible) detailing of waterproofing at the interface between the concrete encasement and the existing surface.
- Anchor head and exposed tendon protection can consist of a plastic or steel casing to allow grouting with a minimum coverage of 50mm and adequate and design working life compatible waterproofing at the interface to any existing or permanent surfaces. For re-stressable anchors a corrosion inhibiting compound should be used. In any case only completely filled encapsulations are acceptable.
- Grout should not be allowed to bleed through the wedges in multi-strand anchor heads.

6.2.4 SUPPLEMENTARY CONSIDERATIONS

6.2.4.1 Class I Encapsulations

For Class I corrosion protection, encapsulations around the tendon may be pre grouted or grouted on-site prior to or after insertion of the tendon into the drill hole.

Special care should be provided for the placement and handling of pre-grouted units prior to emplacement to ensure these do not bend and leave permanent cracks within the corrosion protection grout (or resin). For this reason, the pre grouted anchor must be fully supported at any time from grouting to installation and cannot be lifted or handled without support. Where grouted on-site, care must be taken to leave no voids in the grout.

Centralizers are used inside the encapsulation to ensure grout coverage of the prestressing steel and used outside the encapsulation to provide a minimum 12 mm of grout coverage over the encapsulation.

6.2.4.2 Stray currents

For ground anchor applications in which stray currents are present, tendons should be electrically isolated from the ground environment. Tendons that are encapsulated using a nonconductive sheath, usually plastic, along the tendon bond length and unbonded length are considered electrically isolated. However, for grout protected or epoxy protected tendons, the bearing plate, anchor head, and trumpet should be isolated with insulation from the wall elements.

For tiedown anchors, components of the anchorage should be electrically isolated from the reinforcing steel in the uplift slab.

The effectiveness of the sheath to provide electrical isolation may be verified in the field by testing after installation of the tendon and prior to grouting.

6.2.4.3 Corrosion Protection of Anchors for Structures Subject to Hydrostatic Uplift

The design of a corrosion protection system for anchors used to resist hydrostatic uplift of a structure requires careful attention to prevent water from entering the tendon through a breach in the corrosion protection. Water entering will likely migrate up the tendon to the anchorage between the corrosion protection barrier and the prestressing elements. A Class I protection system is always required for anchors used for this application.

Voids between prestressing elements and between the individual wires of a strand must be completely filled with a corrosion-inhibiting compound and seals provided at the anchor head. Seals at the anchor head must remain watertight after the tendon undergoes elongation during testing or in the event of tendon elongation after lock-off (due to increased uplift loads). In addition, a watertight seal will often be required at the anchorage where the tendon penetrates the structure.

Leakage through penetrations at the anchorage may accelerate corrosion of the anchorage. Seals at the anchorage are more susceptible to leakage under high water pressures. In this case, water tightness testing of seals may be considered prior to construction.

6.2.4.4 Handling and Installation

As there is no redundancy and all corrosion protection layers must be without fault in order to provide protection, special care mut be taken during manufacturing, handling, transport, storage and installation so that no damage occurs. Any damage must be repaired with equivalent protection (including repair joints). Damaged elements cannot be used.

7 CONSTRUCTION

The purpose of this chapter is to provide guidance regarding the construction of ground anchors. This chapter also provides recommendations for minimum requirements of quality assurance / quality control associated with the fabrication, installation, and testing of ground anchors.

7.1 CONSTRUCTION TECHNIQUES

The constraints inherent in the execution of ground anchoring works are an integral part of the anchor and system design and need to be well understood by all parties (designers, constructors, asset owners and the facility maintenance engineers/managers).

7.1.1 PREFABRICATION AND TRANSPORTATION

The majority of anchors are manufactured using either bars, strands or glass / carbon fibres. The prefabrication process of encapsulated tendons is typically undertaken in a controlled factory environment and involves the following:

- Greasing and sheathing strands and/or bars over their free length.
- Installation of grouting tubes and centralisers.
- Installation of corrosion protection systems.
- Pre-grouting (where applicable) of bond lengths within the corrosion protection system.

It should be noted that pre-grouting of the bond length is typically only undertaken with bar anchors and is not recommended for strand anchors, due to the risk of damaging the grout during both lifting of the anchor and transportation. Furthermore, the method of pre-grouting should ensure that the grouted length of anchor is continuously supported along its length during both the grouting, transport and lifting operations.

For bar anchors, the design detailing should ensure the coupler does not bind on the grout column during tensioning, whereby reducing the apparent free length.

7.1.2 DRILLING

The drilling method can have a significant influence on the performance of the anchor and should be carefully selected by appropriately experienced constructors following a review of all available geotechnical information. A construction objective is to avoid ground collapse during drilling and restrict the relaxation of surrounding grounds. The drilling method adopted for the production anchors should be the same as that utilised for the installation of any test anchors on the same site.

The borehole diameter (generally between 125 mm and 250 mm) is constructed using equipment suitable for the ground conditions anticipated. The borehole should be drilled in a way that allows the anchor to be installed without any obstruction. Anchor drilling is generally executed with rotary drilling, rotary percussive or casing methods. Auger or down-the-hole hammer drilling is also possible in stable ground.

A brief description of the common drilling techniques used within the New Zealand construction industry as well as key risk items associated with the drilling of anchors are presented below.

Rotary drilling (with the assistance of air and / or water) is suitable for most ground conditions where the material is competent enough to be free standing and self-supporting. This includes clays and silts, sedimentary rock and volcanic tuff / ash. Care should be taken when drilling through sands with air-flush only as uncased zones of the bore hole can be eroded leading to hole collapse.

Consideration needs to be given to the containment and disposal of drill slurry when drilling with air and water (or where water is encountered in the borehole) to ensure no detrimental impact on the environment. This containment can include simple diversion over ground to a silt pond or transportation via pumping hoses to treatment devices.
Water sensitive soils (eg. loess) are susceptible to water erosion/softening and should be cleaned out with air flush methods only. If the ground is moist, auger drilling could also be considered.

Rotary drilling using augers is suitable for most soil conditions, including sands. However, this method can cause extensive smearing of the borehole in silts and clays if not drilled correctly. Augering has the least impact on the surrounding environment as the hole does not need to be cleaned out with water and compressed air at the end of drilling.

Rotary percussive drilling is suitable in sand and gravel conditions. For self-drilling hollow bar anchors, the grout slurry used for drilling needs to be contained, avoiding any spillages to the surrounding environment.

Down-hole hammer drilling is suitable in rock (particularly Metamorphic) and is an integral part of most overburden casing systems. Environmental considerations when water is encountered are similar to rotary drilling.

Cased drilling is suitable for all ground conditions but noting that if the bond length of soil / weak rock is to be cased there will be a reduction of the bond strength. Environmental considerations are similar to rotary drilling.

Self-Drilling is usually applied in combination with a hollow bar system, using sacrificial drill bits for different ground conditions. A high water : cement ratio grout is used for flushing and drilling and is replaced with the specified permanent grout upon completion. This method provides fluid support during drilling and is suitable in a wide range of conditions. It provides a good grout-ground interface.

The following outlines general key risk items associated with drilling anchors:

- Augering the borehole through wet or damp silts, clays, and most sedimentary rock can result in smearing of the hole and in some cases underperformance of the anchor when compared to a hole drilled under water or air flush. If augering is to be used on site, the investigation anchors should reflect this method.
- Water and air should be used for drilling / flushing / clearing holes (the hole should be filled with water 2-3 times and blown out with air). Misting of water in the drill hole is not recommended.
- Drilling through artesian aquifers requires techniques to equalise water pressure and avoid drill hole collapse.
- Temporary casing may be required over the upper part of the anchor where the ground is not competent enough to be free standing and there is a risk of bore collapse.
- Casing through the bond length needs to be undertaken with caution in certain ground conditions as the casing can effectively smear the borehole resulting in reduced skin friction. Permanent casing of the free length can be considered where grout retention is thought to be at risk, and / or the ground conditions (coupled with site constraints) mean that extraction of the casing would be very difficult.
- Drilling through fractured and/or broken ground (eg highly fractured greywacke) may require the use of grout socks to limit grout loss to ground, if grout socks are used they should be method tested. Alternatively, techniques such as drilling, grouting and re-drilling can be employed to limit grout loss and provide a stable hole.

7.1.3 INSTALLATION AND GROUTING

The anchor is inserted into the borehole using appropriate equipment such as un-coilers, lifting beams, cranes and manual techniques. The primary (or installation) grout is injected into the borehole from the bottom up and depending on the length of the anchor, multiple grout tubes may be necessary to deal with unplanned blockages. Boreholes should be grouted the day they are installed although this can typically be relaxed in hard and competent volcanic rock (and possibly some metamorphic rock, such as Schist) ground conditions with the approval of the design engineer.

Secondary grouting of the anchor free length is not generally required where the anchor free length has been designed to freely elongate (such as greasing and sheathing, petrolatum/tape system etc).

Industry standard grout uses Ordinary Portland Cement with a maximum water : cement ratio by weight of 0.4:1. Additives are required to ensure bleed characteristics are less than 2% and for high specification permanent anchor applications, this needs to be as low as 0-0.5%. High flow additives are essential for anchors that are longer than 20m. If in doubt, the project specification should require grout trial mixes to be undertaken to confirm compressive strength and bleed results. Once production starts, grout cubes should be taken daily or at a frequency determined by the designer in the project specification.

Rotor stator, mono-pump paddle type mixers or high shear colloidal mixers are suitable for the majority of anchor grouting undertaken. Hand mixing and bulk supply through a ready-mix supplier should be avoided.

High-pressure post-grouting can be carried out when bond improvement is required in compressible ground conditions. This grouting can be undertaken using tube-a-manchettes fitted along the outside of the anchor tendon. There are a range of post grouting techniques that can be employed, dependant on the ground conditions and the purpose for which post grouting is employed. The two most common techniques involve a 'bottom-up' grouting technique or a targeted window approach.

It is recommended that grouted anchors are left for at least five days prior to stressing. This delay is to ensure both the tendon-grout and ground-grout bonds have been properly established. Target 28day grout UCS strengths will usually be achieved within 24hours however it can take longer for the grout to ground bond to fully establish.

7.2 CONSTRUCTION QUALITY ASSURANCE / QUALITY CONTROL

Inspections during construction are the primary mechanism to assure that the ground anchors are constructed in accordance with the project plans and specifications. Furthermore, for high-risk applications, short-term and long-term monitoring can be conducted to assess the performance of the anchored system over time.

Inspection activities, if properly conducted, play a vital role in the production of high-quality ground anchors. Ultimately, the ability to demonstrate conformance to project plans and specifications should result in an anchored system that will perform adequately for the intended service life.

Prior to construction, it is important that both the Designer, Contractor and Client understand the project plan and specification requirements for ground anchors, particularly concerning inspection and review responsibilities.

The Designer's Construction Representative (Person responsible on behalf of the designer for on-site inspections) must also understand the proposed construction sequence, anchor construction method as well as the intended function of the anchored system and how it relates back to the design intent along with any critical design aspects and potentially difficult site and subsurface conditions.

Inspection responsibilities should be defined at a pre-construction meeting with the Client and Designer. An example pre-construction checklist is provided in Appendix F.

As a minimum, the following construction QA submittals should be provided to the designer by the constructor prior to the pre-construction meeting.

7.2.1 METHOD STATEMENT

The ground anchor installation method statement should contain the following:

1. Reference to the relevant construction plans and specifications.
2. Mobilisation / demobilisation plan
3. An overview of the proposed construction methods associated with fabrication, Installation, grouting and stressing of ground anchors.
4. The names of key construction persons on site including the driller and designer's site representative.
5. The type, number, and lengths of anchor tendons to be installed including bond length, free length, and stressing / spare length.
6. The proposed fabrication method including whether the anchors are fabricated on-site or off-site. Where pre-grouting of the bond length and / or free is employed, methods to ensure the adequate protection of the bond / free length during transport and lifting / installing into place should be provided which involves continuous support. When strand anchors are used, the individual wires need to be unwound and run through a full immersion grease bath to ensure adequate grease cover to the strand tendon. Additionally, the lateral sheath that houses each strand needs to be sized correctly to ensure the annulus around the strand is not too large and is entirely filled with grease.
7. The proposed drilling techniques, along with anticipated requirements for temporary casing and flush type (if required). It is important that the designer understands the proposed drilling techniques and how they relate back to the design assumptions as some techniques will produce different results in the same ground conditions.
8. The procedure for safely installing the anchor tendon into the bore.
9. The grouting method along with grout batch mix ratios and any additives should be provided.
10. The anchor stressing and testing method including the proposed jack setup arrangement, dial gauge locations and method / records of calibration.

It is recommended that the method statement also contains a ground anchor general arrangement plan, drawn by the constructor, which could include an installation sequence drawing and a typical cross section of the ground anchor showing the bond length, free length and the proposed head works and corrosion protection detailing. The intent is to help demonstrate to the designer that the constructor has understood the design drawings and specifications and to clarify any detailing (particularly around the anchor head and corrosion protection provisions) that may not have been provided in the design drawings.

7.2.2 INSPECTION AND TEST PLAN

As a minimum, the ground anchor inspection and test plan should contain the following:

- Reference to the relevant construction plans and specification.
- Hold point inspection requirements and person responsible for undertaking the check.
- Witness and In-process inspection requirements and person responsible for undertaking the check.
- Proposed method of recording the check or inspection (such as check sheets and anchor record sheets).

It is recommended that the inspection and test plan is always check-linked back to a relevant project specification clause.

7.2.3 QUALITY ASSURANCE / CONTROL – DESIGNER'S SITE REPRESENTATIVES

It is recommended that the designer's site representative responsible for undertaking construction monitoring should be present on site for any investigation or suitability anchor tests (including drilling, installation and testing) and should also attend site at least once to witness the drilling, installation and testing of production ground anchors. The frequency of designer inspections will vary based on the risk level of the anchored structure and will ultimately be determined by the designer.

Designer's site representatives typically require the opportunity to witness and inspect the following:

- Anchor fabrication, greasing and assembly in the factory or on site (at least once).
- Drilling, Installation and testing of investigation and suitability test anchors.
- Drilling, installation and grouting of production anchors on a regular basis.
- Stressing and testing of permanent ground anchors (Acceptance and lift-off tests) on a regular basis.
- Review of all anchor test results before tendons are cut and the anchor head is sealed.

7.2.3 QUALITY ASSURANCE / CONTROL – CONSTRUCTOR

The constructor is responsible for recording and documenting the various stages of anchor construction, installation and testing to demonstrate that the constructed elements meet the requirements of the construction drawings and specification. This process typically includes the following quality documentation:

- Anchor fabrication check sheets.
- Driller's records / logs for drill returns, flush medium, drilling technique (including any casing used), hole depth and whether or not any water was encountered.
- Grouting records (number of cement bags used, target water : cement ratios, bleed test results, cube UCS test results).
- Stressing test records, graphs and proof of lift off-tests.

7.3 TESTING OF GROUND ANCHORS

A key aspect to the design and construction of ground anchors is anchor testing. Anchor testing is carried out to establish or confirm the grout to ground bond presumptive design strengths, the load-deformation behaviour, to verify the installation techniques used by the constructor and to confirm that each anchor installed is capable of resisting the design loads to within acceptable limits.

There are four categories of tests as follows:

1. Investigation tests
2. Suitability Tests
3. Acceptance Tests
4. Lift-off Tests

7.3.1 INVESTIGATION TESTS

Investigation tests (sometimes referred to as pull-out tests or proving tests) are carried out on sacrificial anchors in advance of the construction phase to establish grout to ground bond strengths and load-deformation behaviour of the bond length. An investigation test often involves a number of loading cycles and can include an extended creep test (where ground conditions would indicate the need). A key feature of the investigation test is that the anchor length is typically designed and suitably sized so that it can be stressed to a load which causes the bond-length of the anchor to fail. This will often require upsizing of the anchor bar/tendon and/or modifying the bond length of the anchor to avoid failure of the tendon. It is important to consider the bearing capacity of any reaction frame (ground or structural element) to ensure this does not fail first.

7.3.2 SUITABILITY TESTS

Suitability tests are carried out on permanent anchors to verify the design anchor capacity, load-deformation behaviour and anchor movement are in line with the design intent. Suitability tests are usually carried out on a small percentage of permanent anchors at the start of a project and intermittently thereafter as wall sections progress or ground conditions change. Suitability Tests typically involve 3-6 loading cycles and can include an extended creep test where creep susceptible soils are present or varying ground conditions encountered. The results of the suitability tests may also be used to assist with the interpretation of acceptance tests.

7.3.3 ACCEPTANCE TESTS

Acceptance tests should be undertaken on all anchors and used to 'bed the anchor in' (remove initial compliance between the bond length and ground), to demonstrate that the anchor is capable of resisting the design load, and to verify that the apparent unbonded length is within acceptable limits. Acceptance tests typically involve 1-2 loading cycles and can include a short creep test where needed.

Following a successful acceptance test, the anchor is then 'locked-off' at the design lock-off load (similar to post-tensioning a tendon). In order to check that the anchor has been locked off at the correct load, the first 5% of anchors (or whenever there has been a stressing equipment change) should be re-stressed until the anchorage head begins to 'lift-off' from its housing. The load at which the anchorage head lifts off should be within acceptable limits of the target lock-off load. The practicalities of carrying out this test on a strand anchor needs to be considered as a trestle and feeler gauge are required.

7.3.4 RECOMMENDED TEST FREQUENCIES

Clients may specify testing frequencies (for example Waka Kotahi New Zealand Transport Agency) but in the absence of specific requirements the following minimums are recommended:

- Investigation tests: A minimum three investigation tests are recommended where no previous compatible grout to ground bond history is available.
- Suitability: 5% of the ground anchors or a minimum of three ground anchors, whichever is greater.
- Acceptance Tests: 100% of remaining anchors i.e. anchors subjected to a suitability test do not need to be acceptance tested.

7.3.5 TEST LOADS

For all tests, a maximum anchor test load for each cycle should be established as a function of the design load.

- For investigation tests, the maximum test load is typically the load at which the grout to ground bond is expected to fail, but in any case, not exceeding the allowable capacity of the tendon. Typically, larger tendons are used than expected to be able to test anchor to grout/ground bond strength failure.
- For suitability and acceptance tests, the maximum test load is recommended at 100% of the factored ULS/DCLS seismic or factored static/live loading, whichever is greatest. We don't recommend testing to MCE/CALS load cases for most projects, unless required by the project.
- Extended creep tests for suitability and acceptance tests are typically undertaken at the maximum test load. (Refer to section 6.3.6)
- With respect to setting target test loads and required lock-off loads the following should be taken into account:
- Apparent free lengths should be checked at time of testing – for strand anchors where free lengths are greater than 20 m, the friction properties of the strand/grease/sheath combination when grouted in place must be known (if the sheath is too thin or the greasing is inadequate there can be losses of the stressing load along the free length).
- Strand anchors require a minimum pre-stress of 25% UTS to ensure wedges do not release during reverse loading (a wedge retaining device can be used to reduce this to 15% UTS).
- Account for wedge draw-in during lock off with strand anchors. Generally, a multi-strand jack is used to lock-off strand anchors, however, it is also common practice to use a mono-strand jack to lock of the individual strands.

Recommended test load cycles can be found in Appendix C.

7.3.6 RECOMMENDED TEST ACCEPTANCE CRITERIA

A suitability-tested or acceptance-tested ground anchor with a 10-minute load hold should be acceptable if the:

(1) ground anchor resists the maximum test load with less than 1 mm of movement between 1 minute and 10 minutes; and
(2) total elastic movement at the maximum test load is between 80 percent and 150 percent of the theoretical elastic elongation of the free length.

A suitability-tested or acceptance-tested ground anchor with a 60-minute load hold should be acceptable if the:

(1) ground anchor resists the maximum test load with a creep rate that does not exceed 2 mm between 6 and 60 minutes; and
(2) total elastic movement at the maximum test load is between 80 percent and 150 percent of the theoretical elastic elongation of the free length.

A ground anchor subjected to extended creep testing is acceptable if the:

(1) ground anchor resists the maximum test load with a creep rate that does not exceed 2 mm between 6 and 60 minutes; and
(2) total elastic movement at the maximum test load is between 80 percent and 150 percent of the theoretical elastic elongation of the free length.

The initial lift-off reading should be within plus or minus five (5) percent of the designed lock-off Load. If this criterion is not met, then the tendon load should be adjusted accordingly and the initial lift-off reading repeated.

These creep limits should be adjusted by the designer for anchor systems sensitive to lower creep limits.

7.3.7 PROCEDURES FOR ANCHORS THAT FAIL THE ACCEPTANCE CRITERIA

Anchors that do not satisfy the minimum apparent free length criteria should be either rejected and replaced or, at the discretion of the Designer, locked off at not more than 50 percent of the maximum acceptable load attained. In this event, no further acceptance criteria are applied.

Re-groutable anchors which satisfy the minimum apparent free length criteria, but which fail the extended creep test at the test load may be retrospectively post-grouted and subjected to an enhanced creep criterion. This enhanced criterion requires a creep movement of not more than 1 mm between 1 and 60 minutes at test load. Anchors which satisfy the enhanced creep criterion should be locked off at the design lock-off load. Anchors which cannot be post-grouted or re-groutable anchors that do not satisfy the enhanced creep criterion should be either rejected or, at the discretion of the designer, locked off at 50% of the maximum acceptable test load attained. In this event, no further acceptance criteria are applied. The maximum acceptable test load with respect to creep should correspond to that where acceptable creep movements are measured over the final log cycle of time.

In the event that an anchor fails, the Designer and Constructor should work together to modify the design and / or construction procedures. These modifications may include, but are not limited to, installing additional anchors, modifying the installation methods, reducing the anchor design load by increasing the number of anchors, increasing the anchor bond length, or changing the anchor type. Proposed modifications should not be implemented until the Constructor receives written approval from the Designer.

7.3.8 TESTING AND STRESSING EQUIPMENT

The testing equipment should consist of:

a. A dial gauge capable of measuring to the nearest 0.025 mm to measure the ground anchor movement. Wherever possible, the movement-measuring device should have a minimum travel equal to the theoretical elastic elongation of the total anchor length at the maximum test load and it should have adequate travel so the ground anchor movement can be measured without resetting the device at an interim point.
b. A hydraulic jack and pump to apply the test load. The jack and a calibrated primary pressure gauge should be used to measure the applied load. The jack and primary pressure gauge should be calibrated as a unit by an independent firm. Calibration of all equipment should be current (i.e within a six-month period at the time of usage). Stressing equipment should be capable of tensioning the tendon to more than 80% of the minimum breaking load, ideally in a single stroke. It is important that the jack and gauge are sized to the tendon load, so accuracy of reading is maintained, and this is to cover the situation where a high-capacity anchor is tested to a small load so a different gauge is required. The primary pressure gauge should be not less than 150mm in diameter and graduated so that when the tendon is stressed to 75% of its breaking load, the gauge is reading within plus or minus two (2) percent of the test load.

The stressing equipment should be placed over the ground anchor tendon in such a manner that the jack, bearing plates and stressing anchorage are axially aligned with the tendon and the tendon is centered within the equipment.

The stressing equipment, the sequence of stressing and the procedure to be used for each stressing operation should be determined at the planning stage of the project. The equipment should be used strictly in accordance with the manufacturer's operating instructions.

The equipment should permit the tendon to be stressed in increments so that the load in the tendon can be raised or lowered in accordance with the test specifications and allow the anchor to be lift-off tested to confirm the lock-off load.

8 LONG TERM MANAGEMENT OF GROUND ANCHORAGES

The requirements for Inspection, monitoring, maintenance, and replacement of ground anchors should be determined during the anchor design phase of a project. In particular for pre-stressed anchors, due consideration is required in the design of the anchor head arrangements to allow these to be safely inspected, maintained and decommissioned. These arrangements should be recorded and communicated to the asset owner and operators along with as-built records, specifications and performance details. If such details are not available, such as might exist for historic anchors then specific inspection and testing programmes, beyond the scope of this guide, will be required to be developed if the design performance and design working life are to be verified.

There are a number of comprehensive international guides and documents available that outline industry practice with respect to Inspection and monitoring regimes. The 2020 report by CIRIA (C794) is considered to be a key document and for the purposes of this guide is recommended as a state of practice document to which the reader is referred for detailed guidance.

The inspection and maintenance programmes (frequency and level of detail of the evaluation) for ground anchors should reflect the structural and natural environment within which the anchors have been constructed, their functionality and the critically of their performance (i.e risk and consequence).

Ultimately, through the inspection and monitoring programme, remediation or replacement of anchors may be required. Repair options are usually limited to intervention or replacement in the top 1m of the anchor head, otherwise replacement or supplementary anchors will be required.

Inspection and monitoring regimes are two different processes, outlined in the following sections.

8.1 INSPECTION REGIME

Inspection is generally a simple visual appraisal process that can be included within the routine maintenance programme of the asset(s) by an appropriately qualified/experienced engineer. The two primary aspects to the visual inspection relate to evidence of corrosion and assessment of performance.

8.1.1 VISUAL EVIDENCE OF CORROSION

The integrity of corrosion protection is fundamental to the durability of the anchor. Inspecting and accessing buried and obscured elements of an anchor is extremely difficult and generally requires specialist works. Visual inspection is therefore generally confined to the anchor head assembly. Subject to the performance risks, inspections should involve a programme for intermittent removal of anchor head protective covers and removal (and subsequent re-instatement) of any corrosion inhibiting compounds to allow detailed inspection of the anchor head componentry. A photograph of typical anchor head corrosion is included in Figure 8.1 below.

FIGURE 8.1: **Photograph of corrosion on an anchor head (Auckland).**

The inspection should look for and record evidence of corrosion, or conditions indicative of potential corrosion beyond that expected in the design and detailing of the anchor (including staining, leakage around and from the underside of the anchor assembly and loss of corrosion inhibiting compounds). Where visual inspections identify adverse or progressive corrosion, or conditions indicative of potential corrosion beyond that expected in the design and detailing of the anchor, more thorough and detailed inspections (possibly including intrusive works) may be triggered.

If there is evidence of adverse corrosion or progressive corrosion, then further investigations may also involve re-assessment of the environmental conditions to which the anchor is exposed.

The frequency of the inspection regime must consider the design working life of the anchor, the design working life of the asset, the environmental exposure, the consequences of anchor failure and any evidence of deterioration in performance or durability identified in preceding inspections. In general, it is recommended that anchors are inspected within the first year of installation. Subsequently, where there is high risk of loss of life i.e. Importance Level 3 & 4 structures (by reference to NZS1170) or corrosion affecting the anchor performance, visual inspections should be completed annually. Otherwise, following the first annual inspection a baseline frequency of 5 years should be adopted for all other anchor supported systems unless a higher frequency is required by the asset owner.

8.1.2 VISUAL EVIDENCE OF PERFORMANCE

Visual assessment of the performance of the anchor may be assessed from observation of anchor head or system displacements (e.g. wall, slope or structural displacements). At the anchor head the bearing plate should be locked down and with no play or movement, any rotations in the anchor head should be within the permissible design limits, wedges should be secure with no evidence of slippage, tendon breakage or damage/structural distress to any of the anchor head components.

If structural movements are evident and these movements were not expected, then performance of the anchors may require further evaluation.

1. The results of the inspection may trigger changes to the frequency and / or monitoring programme.
2. Where structural distress or damage, in the anchor or the supported system, are identified then intervention works are more than likely required.

Inspection reporting should reference previous inspection and monitoring findings and provide recommendation for any remediation works and any adjustments to the designed inspection and monitoring programme.

8.2 MONITORING REGIME

Monitoring is distinguished from the inspection and involves testing and/or acquisition of performance data, typically load or deflection. Monitoring is used to verify the performance and, if appropriate, support decisions on the extension of the anchor design working life. Monitoring may be part of a routine programme for higher risk assets as defined at the design stage or as triggered from the findings of inspections.

Monitoring involving load testing of anchors requires that access is available for all, or a representative number of the anchors. Structural form or topography may make such access impractical or difficult. In these instances, monitoring may be undertaken by alternate technologies, such as through load cells, movement/deflection gauging, fibreoptic and remote sensing technology.

Where de-stressing and or lift off testing is incorporated into the monitoring programme then this also affords the opportunity for more detailed visual examination of the system componentry, including to the underside of the anchor head plate.

APPENDICES

APPENDIX A
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APPENDIX B
EXAMPLES OF GROUND ANCHOR CALCULATIONS

[Example calculation to be completed]

APPENDIX C
RECOMMENDED TEST ANCHOR LOADING SCHEDULES

INVESTIGATION TEST

The investigation test should be made by incrementally loading and unloading the ground anchor in accordance with the schedule provided in Table C-1 below. The load should be raised from one increment to another immediately after recording the ground anchor movement. The ground anchor movement should be measured and recorded to the nearest 0.025 mm with respect to an independent fixed reference point at the alignment load and at each increment of load.

The load should be monitored with the primary pressure gauge. At load increments other than the maximum test load, the load should be held just long enough to obtain the movement reading.

The maximum test load in an investigation test should be held for fifteen (15) minutes. The jack should be adjusted as necessary in order to maintain a constant load. The load-hold period should start as soon as the maximum test load is applied and the ground anchor movement, with respect to a fixed reference, should be measured and recorded at 1 minute, 5, 10 and 15 minutes.

The drawings and/or specification should indicate if displacement-time behaviour test is required. This will typically be undertaken at the preliminary design working load of the production anchors and monitored at 1 minute, 5, 15, 50, 150 and 500 minutes.

SUITABILITY TEST

The suitability test should be made by incrementally loading and unloading the ground anchor in accordance with the schedule provided in Table C-2 below. The load should be raised from one increment to another immediately after recording the ground anchor movement. The ground anchor movement should be measured and recorded to the nearest 0.025 mm with respect to an independent fixed reference point at the alignment load and at each increment of load.

The load should be monitored with the primary pressure gauge. The reference pressure gauge should be placed in series with the primary pressure gauge during each suitability test. If the load determined by the reference pressure gauge and the load determined by the primary pressure gauge differ by more than ten (10) percent, the jack, primary pressure gauge and reference pressure gauge should be recalibrated. At load increments other than the maximum test load, the load should be held just long enough to obtain the movement reading.

The maximum test load (MTL) in a suitability test should be held for 10 minutes. The jack should be adjusted as necessary in order to maintain a constant load. The load-hold period should start as soon as the maximum test load is applied and the ground anchor movement, with respect to a fixed reference, should be measured and recorded at

TABLE C-1: Investigation anchor test load schedule

Investigation Test Load Increments (% $F_{U,Tendon}$)							Min Observation Period
Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	
5%	5%	5%	5%	5%	5%	5%	1min
10%	20%	30%	40%	50%	60%	70%	1min
15%	25%	35%	45%	55%	65%	75%	1min
20%	30%	40%	50%	60%	70%	80%	15min
15%	20%	30%	40%	40%	50%	50%	1min
10%	10%	15%	20%	20%	30%	30%	1min
5%	5%	5%	5%	5%	5%	5%	1min

1 minute, 2, 3, 4, 5, 6 and 10 minutes. If the ground anchor movement between 1 minute and 10 minutes exceeds 1 mm, the maximum test load should be held for an additional 50 minutes. If the load hold is extended, the ground anchor movement should be recorded at 15 minutes, 20, 30, 40, 50 and 60 minutes. If the total measured movement over this additional time period does not exceed 2 mm between 6 and 60 minutes then the anchor is considered acceptable with respect to creep.

Table C-2: Anchor suitability test load schedule

SUITABILITY TEST LOAD INCREMENTS (%DL)					
Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
AL	AL	AL	AL	AL	AL
20%	20%	20%	20%	20%	20%
AL	40%	40%	40%	40%	40%
	20%	55%	55%	55%	55%
	AL	40%	75%	75%	75%
		AL	55%	90%	90%
			AL	75%	100% (MTL)
				AL	75%
					AL

AL – Alignment load
DL – Factored Design Load
MTL – Maximum Test Load (for creep testing)

Extended Creep Testing (forming part of the investigation or suitability tests where needed)
The drawings should indicate if extended creep testing is required and select those ground anchors that are to be creep tested. These are typically in cohesive soils and undertaken as part of a suitability or acceptance test. If creep tests are required, at least two (2) ground anchors should be creep tested. The stressing equipment should be capable of measuring and maintaining the hydraulic pressure within 0.35 MPa.

The extended creep test should be made by incrementally loading and unloading the ground anchor in accordance with the suitability test schedule provided above. At the end of each loading cycle, the load should be held constant for the observation period indicated in the creep test schedule provided in Table C-3 below. The times for reading and recording the ground anchor movement during each observation period should be 1 minute, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30, 45, 60, 75, 90, 100, 120, 150, 180, 210, 240, 270 and 300 minutes as appropriate for the load increment. Each load-hold period should start as soon as the test load is applied. In a creep test, the primary pressure gauge and reference pressure gauge will be used to measure the applied load and if required a load cell can be used to monitor small changes in load during constant load-hold periods. The jack should be adjusted as necessary in order to maintain a constant load. At the designer's discretion, if the anchor hasn't moved during the lower time increments the need for 300 minute observation can be reassessed.

The Constructor should plot the ground anchor movement and the residual movement measured in an extended creep test. The Constructor should also plot the creep movement for each load hold as a function of the logarithm of time.

Table C-3: Anchor extended creep test load schedule

EXTENDED CREEP TEST LOAD SCHEDULE (%DL)			
Load Cycle	Maximum Cycle Load	Total Observation Period	Movements measured at following times (min)
1	20%	10min	1, 2, 3, 4, 5, 6, 10
2	40%	30min	1, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30
3	55%	30min	1, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30
4	75%	45min	1, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30, 45
5	90%	60min	1, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30, 45, 60
6	100%	300min	1, 2, 3, 4, 5, 6, 10, 15, 20, 25, 30, 45, 60, 300

DL – Factored Design Load

Acceptance Test
The acceptance test should be performed by incrementally loading the ground anchor in accordance with the schedule provided in Table C-4 below. The load should be raised from one increment to another immediately after recording the ground anchor movement. The ground anchor movement should be measured and recorded to the nearest 0.025 mm with respect to an independent fixed reference point at the alignment load and at each increment of load. The load should be monitored with the primary pressure gauge. At load increments other than the maximum test load, the load should be held just long enough to obtain the movement reading.

The maximum test load in an acceptance test should be held for ten (10) minutes. The jack should be adjusted as necessary in order to maintain a constant load. The load-hold period should start as soon as the maximum test load is applied and the ground anchor movement with respect to a fixed reference should be measured and recorded at 1 minute, 2, 3, 4, 5, 6 and 10 minutes. If the ground anchor movement between 1 minute and 10 minutes exceeds 1 mm, the maximum test load should be held for an additional 50 minutes. If the load hold is extended, the ground anchor movements should be recorded at 15 minutes, 20, 30, 40, 50 and 60 minutes. If the total measured movement over this additional time period does not exceed 2mm between 6 and 60minutes then the anchor is considered acceptable with respect to creep.

Table C-4: Anchor acceptance test load schedule

ACCEPTANCE TEST LOAD INCREMENTS (%DL)	
Cycle 1	**Cycle 2**
AL	AL
20%	20%
40%	40%
55%	55%
75%	75%
90%	90%
100% (MTL)	100% (MTL)
75%	75%
AL	AL

AL – Alignment load
DL – Factored Design Load
MTL – Maximum Test Load (for creep testing)

Lift off Test
After transferring the load to the anchorage, and prior to removing the jack, a lift-off test should be conducted to confirm the magnitude of the load in the anchor tendon. This load is determined by reapplying load to the tendon to lift off the wedge plate (or anchor nut) without unseating the wedges (or turning the anchor nut). This moment represents zero time for any long-time monitoring.

APPENDIX D
TYPICAL BOND CAPACITIES OF KNOWN NEW ZEALAND ROCKS AND SOILS

Table D-1 and D-2 provide typical bond capacities for predominant rocks and soils in New Zealand. Note these are taken from a sample of testing data that has been completed in New Zealand and use of these test values for design should only be used for preliminary design. Site specific testing should always be completed for a ground anchor design as the design ground-grout bond strength is highly influenced by local conditions.

Table D-1: Typical Anchor Bond Presumptive Capacities in Rock

ROCK	WEATHERING	ROCK QUALITY GSI	CONSTRUCTION METHODOLOGY	ULTIMATE BOND CAPACITY (MPA)	LOCATION TESTED
Greywacke sandstone	UW -SW	40-50	Downhole hammer	0.74 to 1.1	Kaikoura
	MW		Downhole hammer (air and water flush)	0.8 to 1.0	Wellington
	SW-MW	20-40	Downhole hammer and self drilled with grout flush	0.3 to 0.8	Kaikoura
	HW		Downhole hammer (air and water flush)	0.2 to 1.0	Thames/ Wellington
	HW and colluvium		Self drilled with grout flush	0.2 to 0.5	Kaikoura
	CW			0.11 to 0.5	Wellington
Sandstone			Dragbit (air and water flush)	1.0 to 2.0	Auckland
			Auger	0.5	Auckland
	HW		Auger	0.2	Auckland
Schist			Downhole hammer	1	Queenstown
Basalt	HW		Downhole hammer/Dragbit air and water flush	0.6 to 2.0	Northland
Ignimbrite			Dragbit (air and water flush)	0.49	Taupo
Northland Allochthon			Dragbit (air and water flush)	0.55-1.05	Auckland
ECBF			Downhole hammer (air flush)	1.0 to 1.4	Auckland
			Auger	0.76	Auckland
Waitemata Group	RS		Dragbit (air and water flush)	0.2	Auckland
			Auger	0.065	Auckland
Red Scoria			Downhole hammer and casing	0.3	Auckland
Basalt boulders / rubbly basalt			Downhole hammer and casing	0.8	Auckland

Note: GSI and weathering can have a large effect on the rock-grout bond strength.

Table D-2: Typical Anchor Bond Presumptive Capacities in Soil

SOIL	DENSITY/ STRENGTH	CONSTRUCTION	ULTIMATE BOND CAPACITY (MPA)	LOCATION TESTED
Sandy silty gravel	Very dense / compact	Drill and grouted	0.4	Kaikoura
		Down hole hammer and casing	0.5	Timaru/ Queenstown
Silty sand	Stiff		0.15	
Clay/silty sand		Auger (post-grouted)	0.08	Whangarei
Dune sands	Loose	Auger	0.03 to 0.06	Waikanae / Otaki
Gravelly/clayey sand		Pneumatic downhole hammer and hollow bars with sacrificial drill bit	0.13 to 0.3	Wellington
Tauranga Group – Puketoka Formation		Dragbit (air and water flush)	0.02 to 0.2	Auckland
Puketoka sands	Dense	Drag bit (continuous casing) Post-grouted	>0.26	Auckland
Ash/tuff/clay		Dragbit (air and water flush)	0.25	Auckland
Clay	Very stiff	Dragbit (air and water flush)	>0.075 to 0.15	Waiheke Island/ Raglan
	Stiff	Auger	>0.95	Christchurch
Glacial Till (silt/ sand/ gravel)	Very dense	Dragbit (air flush) with casing	0.2 to 0.3	Queenstown
		Dragbit (air flush) with casing and post grouted with TAM	0.38 to 0.47	Queenstown
Northland Allochthon weathered soils		Dragbit (air and water flush)	0.185	Silverdale

APPENDIX E
STANDARD DRAWING DETAILS/PHOTOS

WORK IN PROGRESS

APPENDIX F
PRE-DESIGN, DESIGN AND CONSTRUCTION CHECKLIST

PRE-DESIGN	CLIENT	CLIENT'S DESIGNER[9]	GROUND ANCHOR DESIGNER
Has adequate geotechnical site investigations been carried out to sufficiently characterise the site and establish the depth, strength and thickness of founding layers?			
Have Ground Anchors been evaluated for suitability with respect to both geotechnical conditions and structural requirements?			
Has the ground anchor designer been agreed with the Client (i.e. Clients consultant to design or Design and Construct contract)?			
Have the Client's requirements, design load cases, site constraints been adequately determined and advised?			
Who is responsible for providing the following information? 1. Design working life 2. Design Loads and requirement for load testing 3. Tendon types, bond lengths and free lengths and anchor spacings 4. Durability and corrosion protection 5. Requirement for long term monitoring and maintenance inspections 6. Load-transfer mechanism from anchor to structure			

DESIGN	CLIENT	CLIENT'S DESIGNER[9]	GROUND ANCHOR DESIGNER
Has the Ground Anchor Designer agreed adequate geotechnical site investigations have been carried out to prove the depth, strength and thickness of founding layers, and other such loads as landslide and liquefaction? If not, Ground Anchor Designer should advise and undertake as considered necessary.			
Does the Ground Anchor Designer have all the required design documents?			
Has the Ground Anchor Designer evaluated and allowed for all geotechnical requirements? 1. All potential failure mechanisms including bearing, punching, pull out, lateral loads, and capacities 2. Seismic effects such as liquefaction, reverse loading and lateral loading 3. Settlements 4. Capacity based on analytical assessment or by direct comparable experience with projects in similar ground conditions			

DESIGN	CLIENT	CLIENT'S DESIGNER[9]	GROUND ANCHOR DESIGNER
Has the Ground Anchor Designer evaluated and allowed for all design and construction loadings? 5. With the structure cope with predicted settlements 6. Structural capacity of tendon 7. Corrosion protection 8. Anchor spacings and minimum free length 9. Load transfer into structural element during testing			
Interaction with the structure and any long-term access constraints			
Design strength reduction factor and degree of load testing agreed			
Has a PS1 (and PS2 if required) been completed by Chartered Professional Engineer and approved by the Local Authority?			
Professional indemnity insurance limit and cover agreed			
Specification for monitoring and maintenance of ground anchors			
Has construction monitoring been established by the design engineer?			
Has the Contractor's experience been verified?			

CONSTRUCTION	CLIENT	CLIENT'S DESIGNER[9]	GROUND ANCHOR DESIGNER
Has the contractor made an assessment of investigation data in relation to design assumptions? Is additional site-specific testing required?			
Is the Client aware of risks in the ground (e.g. grout loss and instability of drill hole) and have these been qualified by the Contractor?			
Has the constructor provided the following minimum details for evaluation by Ground Anchor Designer and / or Client? 1. Project reference list of at least 5 similar projects within the last 5 years 2. Resumes of construction team 3. Working drawing showing 1. Ground anchor numbering / reference system 2. Ground anchor tendon and corrosion protection system 3. Tendon capacity versus design loads 4. Certificates of compliance for anchor system materials 5. Calibration details of anchor testing equipment 6. Inspection and test plan 7. Proposed QA documentation			
If Investigation Tests and / or Suitability Tests undertaken in advance of production works, do they prove compliance with design requirements? If not, have changes been made and approved?			
Has the contractor provided Ground Anchor Construction Records including fabrications sheets, drilling and installation logs, tensioning records and as-builts (if needed)?			
Has construction monitoring been carried out by the design engineer?			

APPENDIX G
DESIGN CO-ORDINATION STATEMENT EXAMPLE

EXAMPLE OF STATEMENT OF DESIGN CO-ORDINATION

Job. No. ____________________

Date: ____________________

[Name of receiving party] by [Letter or email]

Attention: [Receiving representative]

Dear [Name]

[Author’s Discipline] Design Coordination Statement for [Project Name]

Statement of Co-ordination:

This [Author’s Discipline] Design Coordination Statement is provided to the Building Consent Authority and is intended to accompany documents submitted for the building consent application for the design of [Project name].

During the detailed design process, we have liaised with the [Other’s Discipline] Engineers to ensure that [Author’s Discipline] aspect of the design have been considered by them.

On the basis of the above, we therefore consider that we have reasonable grounds to believe that the relevant [Other’s Discipline] designs complement the [Author’s Discipline] designs carried out.

Signed by:

____

[Print Name]

[Title]

On behalf of [Name of Company]


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