THE ANCHORAGE OF REINFORCEMENT AND FIXINGS IN HARDENED CONCRETE

1. INTRODUCTION

Background

In recent years there has been an increase in the use of resin anchored reinforcement and fixings in works relating to highway structures. The anchorage of reinforcement and fixings in drilled holes using resin or cement based grout can offer a cost-effective solution for making attachments or extensions to existing concrete structures. The use of this technique can mitigate the need for extensive breakout of the parent concrete. It can also have benefits in terms of reducing disruption to the highway network, reducing requirements for traffic management and reducing the duration of the construction programme. However, the design methodology for the anchorage of reinforcement/fixings (using resin or cement based grout) is not covered in existing design standards. In addition, with the exception of some specific applications, the Specification for Highway Works does not include clauses covering work of this nature. It has therefore been necessary to submit Departures from Standard for the anchorage of reinforcement/fixings in hardened concrete where their use is proposed on highway structures works. The Departure from Standard submissions have had to address the design methodology and the proposed specification.

Scope

This Transport Scotland Interim Amendment (TS IA) covers the design and specification of bonded fixings and reinforcing bars. Mechanical anchors are not covered by this TS IA. It should be noted that torque controlled bonded anchors are considered to be mechanical anchors for the purpose of this TS IA. Any proposal to use anchors of a type not covered by this TS IA should be submitted for consideration through Transport Scotland's Departures Approval System. Such proposals will be considered on their merits taking account of project specific circumstances.

This TS IA does not cover post-drilled anchorages for vehicle restraint systems, permanent bollards, traffic signs, lighting columns or CCTV masts. These applications are addressed in other implemented standards and/or the Specification for Highway Works.

Purpose

The purpose of this TS IA is to set out design methodologies and model specification clauses that are acceptable to Transport Scotland. Many suppliers of proprietary grouts and anchorage systems have produced design guidance relating to their products. However, there is considerable variance in design methodology and the factors of safety recommended by manufacturers. An objective of this TS IA is to promote an appropriate and consistent approach in terms of design methodology and specification.

Implementation

Where this TS IA is referenced in an Approval in Principle submission (or in a Category 0 Design and Check Certificate) and proposals for the anchorage of reinforcement/fixings are fully consistent with the recommendations of this TS IA, it will not be necessary to submit a Departure from Standard application. It is recognised that there may be circumstances in which it will be necessary to depart from this TS IA. In these circumstances, a Departure from Standard application should be submitted for consideration. The submission of a Departure from Standard will afford Transport Scotland an opportunity to review the proposed design methodology and/or specification against the intended application.

European Technical Approvals

The European Organisation for Technical Approvals (EOTA) has produced a series of Guidelines for European Technical Approvals (ETAGs). These documents set test and assessment criteria for products. ETAG 001 'Metal Anchors for Use in Concrete' relates to anchors installed in drilled holes in concrete. Products complying with ETAG 001 can be awarded a European Technical Approval (ETA) and will have a European Technical Approval Certificate. To obtain a CE mark, an anchor must have an ETA and Attestation of Conformity. The latter includes factory control and supervision requirements. It is not mandatory for products used on Transport Scotland's works to have a European Technical Approval. However, the use of products with European Technical Approvals provides additional assurance regarding the suitability of the product. This is reflected in the design methodology proposed in this TS IA, which facilitates the adoption of different partial material factors for products with European Technical Approvals.

The relevant parts of ETAG 001 are:

Part 1	'General'(1)
Part 5	'Bonded Anchors'(2)
Part 6	'Anchors for Multiple Use for Non-structural Applications'(3)
Annex A	'Details of Tests'(4)
Annex B	'Admissible Service Conditions'(5)
Annex C	'Design Methods for Anchorages'(6)

Note: ETAG documents are available from the European Organisation for Technical Approvals (EOTA) website: www.eota.be.

Some of the requirements of Part 6 are less onerous than the equivalent requirements of Part 1 and/or Part 5. Part 6 is intended for use in non-structural applications (e.g. duct supports) where excessive slip or failure of one anchor would not significantly affect performance under the serviceability or ultimate limit states. Further, Part 6 is only applicable in circumstances that are consistent with the definition and criteria agreed by the UK (See Annex 1 to ETAG 001 Part 6).

Future Developments

ETAG 001 Part 5 'Bonded Anchors' is currently under revision in response to developments in the technology of resin anchoring systems.

A CEN Standard 'Design of Fastenings for use in Concrete' is currently under development. It is expected that Transport Scotland will implement the CEN standard in due course. It should be noted that a European Technical Approval is likely to be required for the design of bonded anchors to the CEN standard.

With respect to the anchorage of reinforcement in existing concrete, an EOTA Technical Report 'Assessment of post-installed rebar connections'(14) has recently been published. The Technical Report sets out a design methodology for anchored reinforcement aligned to Eurocode 2. Transport Scotland's requirements for the use of EOTA Technical Report TR023 for designs to Eurocode 2 have yet to be determined.

BS EN 1504 Part 6 'Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity – Part 6:

Anchoring of reinforcing steel bar'[13] also covers anchored reinforcement. Transport Scotland's requirements for the implementation of BS EN 1504 Part 6 for concrete repair works have yet to be determined.

Definitions
This is not an exhaustive list of definitions for terms used in this IAN. The following definitions are provided in order to clarify particular terms which are open to different interpretations.

The **characteristic failure** load of an anchorage for a specific failure mode is the lower 5% fractile for a confidence level of 90% determined from product testing.

Resin grout includes predominantly synthetic mortars in glass capsules, soft skin capsules, injected from cartridges or bulk poured.

A **torque-controlled bonded** anchor is an anchor placed into a cylindrical hole, with load transfer achieved by a combination of bonding and expansion.

2. APPLICATIONS OF THE TECHNIQUE (SAFETY CRITICAL AND NON-SAFETY CRITICAL)

The anchorage of reinforcement and fixings in drilled holes has been adopted for a wide range of applications. These include; fixing ancillary equipment to concrete surfaces, attaching environmental barriers to structures, provision of extensions to concrete elements (eg. construction of new parapet upstands), strengthening/extending foundations and substructures, fixing temporary works to the edge of bridges to facilitate parapet replacement, and attaching walkways to the sides of structures.

Prior to using post-drilled anchorages for any application careful consideration must be given to the potential implications of drilling into the structure (e.g. possible damage to reinforcement, prestressing tendons etc.).

It is important to recognise that the implications of an individual anchor failing to perform as expected in service are dependent on the proposed application. For example, if a structure is extended by anchoring a large number of reinforcing bars into the existing concrete, an individual anchored bar with sub-standard capacity is unlikely to have significant implications. In contrast, if temporary works are attached to the side of a bridge by a small number of fixings, failure of an individual fixing could be very significant and may have severe consequences. The latter example is considered to be a 'safety critical' application. The safety critical nature of the proposed application needs to be taken into account in the design methodology and testing regime adopted. Typical examples of safety critical and non-safety critical applications are given in Table 2.1.

It should be noted that there is relatively little information available regarding the behaviour of resin anchorages subject to significant cyclic, fluctuating or pulsating loads. There is therefore more uncertainty about the performance of resin anchorages over time under such loading conditions. Again, this should be considered in the selection of an appropriate design methodology and testing regime. Anchorages subject to significant cyclic, fluctuating or pulsating loads should generally be treated as 'safety critical' applications.

Description	Are safety risks sensitive to the performance of a small number of anchorages?	Are the anchorages subject to significant cyclic loading?	Classification (follows from the answers to the questions in the columns to the left)
Strengthening a pier for impact by constructing a reinforced concrete plinth around existing columns with reinforcing bars anchored into the existing foundation.	No	No	Non-safety critical
Temporary works suspended from the side of a bridge deck to facilitate parapet replacement. The temporary works will be supported by fixings anchored into the edge of the bridge deck.	Yes	No (Wind loads will generate fluctuating stresses, but the temporary works will only be in place for short duration)	Safety critical
Service duct suspended from a bridge deck. The duct will be attached to the deck with resin anchors.	No (If failure of an individual fixing would lead to a section of the duct falling from the bridge and this presents a significant safety risk then the answer would be Yes)	No	Non-safety critical (If failure of an individual fixing would lead to a section of the duct falling from the bridge and this presents a significant safety risk then the application would be classified as safety critical)
Environmental barrier fixed to the edge of a bridge deck using resin anchors.	Depends on whether the failure of a support presents a significant safety risk (e.g. barrier could fall onto live carriageway below)	Yes	Safety critical
Construction of a continuous parapet plinth along the length of a bridge. The plinth will be attached to the existing deck with resin anchored reinforcing bars.	No (If the plinth was fixed to the deck by a small number of bars local to individual parapet posts then the answer would be Yes)	No (Cyclic stresses are low compared with the stresses generated by vehicle impact with the parapet)	Non-safety critical (If the plinth was fixed to the deck by a small number of bars local to individual parapet posts then the application would be classified as safety critical)

Note: Where safety risks are sensitive to the performance of a small number of anchorages, the application may be categorised as non-safety critical if redundancy is built into the design (e.g. provision of five anchors where the design requires four).

Table 2.1: Typical Examples of Safety Critical and Non-safety Critical Applications

3. DESIGN

General

Anchorages shall be designed using a limit state approach. Design actions at ULS and SLS should be evaluated and compared with design resistances and relevant SLS criteria.

The performance of anchorages installed in hardened concrete can be sensitive to the quality of workmanship during installation. Against this background, appropriate factors of safety should be adopted and load testing of installed anchorages will almost always be required. Whilst it is important to ensure that anchorages are designed with adequate factors of safety, the use of excessive anchorage lengths should be avoided in order to mitigate health and safety risks associated with drilling operations on site. Given that the performance of anchorages can be sensitive to workmanship, the use of personnel properly trained in the techniques of anchor installation is recommended.

The design methodologies set out in this TS IA, which are broadly based on ETAG 001, involve using manufacturer's load capacity/deformation data (derived from testing). Different performance data is often provided depending on whether the anchorages are to be installed in non-cracked or cracked concrete. It is important to ensure that the appropriate capacity data is used for design purposes. A UK guidance document 'Use of Anchors with European Technical Approvals. UK Guidance – Distinction between cracked and non-cracked concrete-'[7] published by the UK National Technical Committee – Anchors includes advice on this issue that will enable the designer to determine whether non-cracked or cracked conditions should be considered.

Partial Material Factors for ULS Verification

The partial material factors for concrete/grout related failure modes (concrete cone failure, concrete splitting failure, pull-out and concrete pryout/edge failure) to be used to evaluate the design resistance of anchorages subject to static or quasi-static actions are given in Table 3.1. For anchorages subject to significant cyclic, fluctuating or pulsating loads the partial material factors applicable to safety critical applications should be used. Where a product has a valid ETA Certificate for the proposed application, the partial material factors given in the ETA Certificate may be used as an alternative to those shown in Table 3.1 provided that design is carried out in accordance with ETAG 001 Annex C.

Partial material factors given in ETA certificates for use in conjunction with Annex C of ETAG 001 do not distinguish between safety critical and non-safety critical applications. However, ETAG 001 and the associated design methods are intended for anchors, the failure of which would cause risk to human life or have considerable economic consequences. On this basis, the methods set out in ETAG 001 are considered appropriate for safety critical applications and conservative for non-safety critical applications.

	Safety Critical	Non-safety Critical
Tension (γ_{Mc}, γ_{Msp} and γ_{Mp})	2.16	1.80
Shear (γ_{Mc})	1.80	1.50

Table 3.1: Values for γ_{Mc}

Partial material factors relating to failure of metal components (e.g. reinforcement) should be taken from relevant standards. Alternatively, where a product has a valid ETA certificate, the design resistance may be calculated in accordance with ETAG 001 Annex C using data from the ETA Certificate.

SLS Criteria

It is important to consider the deformation of anchors under SLS loads in order to ensure that structural performance, appearance and durability are not impaired. In many applications (e.g. temporary works fixings, strengthening a structure to accommodate accidental loading etc.) deformation control is unlikely to be critical. However, in other cases (e.g. anchored reinforcing bars subject to long-term loads), careful control of deformation will often be of greater significance. Table 3.2 gives upper bound deformation limits for short and long-term loading at SLS. The limits in this table are recommended in circumstances where there are no particular adverse implications associated with displacement under load. Where displacement would have significant implications, the designer should adopt alternative application specific limits as appropriate.

	Maximum deformation under short-term loading	Maximum deformation under long-term loading
Tension	0.05d	0.12d
Shear	0.20d	0.30d

Notes:
d is the nominal diameter of the bar, bolt or stud.
Short-term deformation limits should be met at temperatures up to the maximum concrete temperature derived in accordance with BD 37. This may conservatively be taken as 60 ^{o}C.
Long-term deformation limits should be met at temperatures up to 0.6 times the maximum concrete temperature derived in accordance with BD 37. This may conservatively be taken as 36 ^{o}C.

Table 3.2: Upper bound deformation limits δ

Testing

It is recommended that preliminary load tests on trial anchorages are carried out. In the event that this preliminary load testing does not produce satisfactory results, there is then the opportunity to take corrective action (e.g. increasing the embedment depth) before installing the works anchorages. Further tests on works or sacrificial anchorages can be carried out as work proceeds. Tests on sacrificial anchorages (as opposed to works anchorages) should be considered when testing works anchors is not possible due to geometric constraints (e.g. restricted access or bent bars). Where testing of sacrificial anchorages is proposed in lieu of testing works anchorages, ensuring an appropriate quality of workmanship for the works anchorages is particularly important. Tests on trial or sacrificial anchorages should, as far as reasonably practicable, replicate the conditions and installation methods applicable to the works anchorages. Wherever possible, trial/sacrificial anchorages should be located on the structure in the vicinity of the proposed works anchorages.

The recommended load test is based on the requirements of BS 5080 Part 1[(8)]. The test arrangement set out in BS 5080 Part 1 involves applying an axial tensile load to a threaded component. This requires some modification when testing ribbed reinforcing bars. Two approaches to testing are currently in use for anchored reinforcing bars. The first involves cutting a thread into the exposed end of the bar. Load is then applied to the bar by means of a nut on the threaded section of bar. This approach is usually limited to tests on trial/sacrificial anchorages. The second approach is to apply a coupler to the bar and to apply load to the bar via the coupler. This approach can be used for testing trial, sacrificial or works anchorages. Note: Careful consideration should be given to safety during load testing. In particular, any proposal to apply load to a bar via a coupler should be considered in consultation with the manufacturer of the coupler.

It is recommended that 5 tests are initially carried out on trial anchorages. The number of subsequent load tests shall be a minimum of 3% (10% for safety critical applications) of the total number of anchorages proposed in the works, subject to a minimum of 3 anchorages for each size and type of anchorage.

BS 5080 Part 2[(9)] includes details of a shear test for anchored fixings. Although the shear test provides a more direct indication of the shear capacity for fixings subject to shear, the axial test is more readily undertaken on site and is considered to provide an appropriate level of assurance regarding quality of workmanship.

Design Life

The anchorage should have an expected working life consistent with the required design life for the works. ETAG 001 requires products to be suitable for an intended working life of at least 50 years. This requirement has been adopted as the default requirement in model specifications included in Annex A to this TS IA. Where a longer working life is required this should be clearly specified. Where reuse of installed fixings is proposed or the design loads on existing fixings are increased the fixings may be used when approved through the Departure from Standards process. Note: The condition of accessible anchorages in service shall be monitored as part of the routine inspections undertaken at the structure in which they are installed.

Other Considerations

Wherever possible multiple drilled holes should be staggered in order to avoid creating a line of perforations in the existing concrete.

Where a hole has to be re-drilled/cored (e.g. due to an obstruction being encountered or defective concrete being identified) consideration should be given to the influence of the aborted hole (which should be repaired) on the performance of the relocated anchor. Where obstructions such as existing reinforcement are anticipated the design of brackets/base plates should take account of the need to relocate anchors.

Global or local structural integrity should not, under normal circumstances, rely on the performance of a single anchorage.

If it is proposed to install anchorages in repaired concrete surfaces then consideration should be given to the potential for a plane of weakness to exist at the interface between the repair concrete and the substrate concrete. For shallow repairs one possible approach is to ignore that part of the embedment length, which lies within the repair concrete. However, for proprietary anchors with a fixed embedment depth advice will then need to be sought from the manufacturer regarding the effect on anchor performance. Ignoring the embedment depth in the repair concrete may also be appropriate for deeper repairs. However, whether or not this is appropriate will depend on the particular circumstances and requires careful consideration. In cases where ignoring the contribution of the repair material in the design of the anchor is not feasible (e.g. installing an anchor in a thin section) consideration should be given to investigating the integrity of the interface between original and repair concrete.

Given the safety factors incorporated in the recommended design methodolgy, it is unlikely that failure of an appropriately installed anchorage will occur in service. However, in the event of a load substantially greater than the ULS design load being applied to the anchorage then failure is possible and could take the form of a concrete failure. In circumstances when this would be particularly problematic (e.g. the structural integrity of the bridge could be compromised) it would be prudent to ensure that an upper limit on the strength of the fixing is introduced to ensure that the metal component fails at a lower load than that required to generate a failure in the substrate concrete.

In circumstances where loads to be carried by anchorages have been evaluated in advance, but the Contractor is required to select a proprietary product suitable for the applied loads, the following design information should be provided for the Contractor:

- The classification of the application (safety critical or non-safety critical).
- Design actions at ultimate limit state and serviceability limit state.
- The classification of the concrete (cracked or non-cracked).
- Minimum and maximum concrete temperatures.
- The characteristic concrete cube strength to be used in the design of the anchorage.
- Any application specific criteria relating to embedment depth, such as a maximum embedment depth, or a pre-determined embedment length.
- Details of the metal component when this has been pre-determined (e.g. type of reinforcing bar).
- Displacement limits for short and long-term loads at serviceability limit state.
- For anchorages subject to axial tension, a minimum value for the test load.
- The number of tests to be carried out prior to approval and during the installation of works anchorages.

Design Process for Anchorages Subject to Axial Tension

The following design approach should be adopted for anchorages in which the principal load effect is axial tension:

Step 1

Determine whether the proposed application is safety critical or non-safety critical with reference to the guidance in Section 2.

Step 2

Evaluate design actions for ULS ($N_{Sd,uls}$) and SLS ($N_{Sd,sls}$) in accordance with relevant standards.

Step 3
Decide whether the concrete is cracked or non-cracked (Note: Advice is given in BBA document 'Use of Anchors with European Technical Approvals'[7]).

Step 4
Evaluate the maximum and minimum concrete temperatures in accordance with BD37(11). Alternatively, a minimum concrete temperature of -31^{O}C and a maximum concrete temperature of +60^{O}C may be assumed.

Step 5
Extract characteristic resistances for all relevant failure modes excluding metal component failure (i.e. pull-out failure, concrete cone failure and concrete splitting failure) from manufacturer's data (or an ETA Certificate valid for the proposed product/application) for the relevant range of temperatures.

Step 6
For each failure mode, the design resistance is obtained by dividing the characteristic resistance by the appropriate partial material factor (See Section 3) and applying modification factors recommended by the manufacturer as appropriate to take account of:

- Characteristic strength of the concrete. Note: In circumstances where it is inappropriate to make a conservative assumption regarding the strength of the parent concrete, it may be necessary to undertake testing to determine concrete strength
- Embedment depth
- The influence of edge distance and spacing
- Cracked/non-cracked conditions
- Member thickness
- Any other influencing factors identified by the manufacturer

Note: Where characteristic resistances are extracted from a valid ETA Certificate design resistances shall be determined in accordance with ETAG 001 Annex C.

Note: In some cases, characteristic capacities quoted in manufacturer's data (or given in ETA Certificates) take account of certain influencing factors (e.g. cracked or non-cracked concrete conditions, concrete strength etc). Where this is the case there is no need to take these particular factors into account separately. However, it is important to be satisfied that all relevant influencing factors have been taken into account.

Step 7
Evaluate the design resistance of the metal component in accordance with relevant standards. For example, in the case of a ribbed reinforcing bar subject to static or quasi static loading, the tensile design resistance is determined in accordance with BS 5400 Part 4 as the characteristic yield strength of the bar divided by the appropriate partial material factor. Where the product has an ETA Certificate valid for the proposed application the design resistance of the metal component may be calculated in accordance with ETAG 001 Annex C using data from the ETA certificate.

Step 8
The tensile design resistance ($N_{Rd,uls}$) of the anchor is taken as the lowest design resistance obtained for the various failure modes (including metal component failure). Compare $N_{Rd,uls}$ with $N_{Sd,uls}$.

Step 9
With reference to load/displacement data provided by the manufacturer (or data given in an ETA Certificate valid for the proposed product/application), check that predicted displacement for SLS action under short and long-term loads is acceptable.

Note: Where load/displacement data for ribbed reinforcing bars is not available, data relating to threaded rod may be used for checking compliance with SLS deformation limits. In addition, where load/displacement data for the particular embedment depth/concrete strength/bar diameter is not available, data applicable to a smaller embedment depth/lower concrete strength/smaller bar diameter may be used.

Note: When using load/displacement data in an ETA certificate to verify compliance with SLS deformation limits, it may be assumed that displacement is proportional to applied load.

Step 10
Evaluate the test load to be applied. The test load applied to installed anchorages on site should be a minimum of 1.1 times the ULS design action (i.e. $1.1N_{Sd,uls}$), but should not exceed 1.1 times the ULS design resistance (i.e. $1.1N_{Rd,uls}$).

Design Process for Anchorages Subject to Shear Forces
The following design approach should be adopted for anchorages in which the principal load effect is shear:

Step 1
Determine whether the proposed application is safety critical or non-safety critical with reference to the guidance in Section 2.

Step 2
Evaluate design actions for ULS ($V_{Sd,uls}$) and SLS ($V_{Sd,sls}$) in accordance with relevant standards.

Step 3
Decide whether the concrete is cracked or non-cracked (Note: Advice is given in BBA document 'Use of Anchors with European Technical Approvals'(7)).

Step 4
Not applicable

Step 5
Extract characteristic resistance data for relevant failure modes excluding metal component failure (i.e. concrete pry-out failure and concrete edge failure) from manufacturer's data (or an ETA Certificate valid for the proposed product/application).

Step 6
For each failure mode, the design resistance is obtained by dividing the characteristic resistance by the appropriate partial material factor (See Section 3) and applying modification factors recommended by the manufacturer as appropriate to take account of:

- Characteristic strength of the concrete. Note: In circumstances where it is inappropriate to make a conservative assumption regarding the strength of the parent concrete, it may be necessary to undertake testing to determine concrete strength.
- Embedment depth
- The influence of edge distance and spacing
- Cracked/non-cracked conditions
- Member thickness
- Load application arrangement (eccentricity, restraint conditions etc.)
- Load direction
- Any other influencing factors identified by the manufacturer

Note: Where characteristic resistance data is extracted from a valid ETA Certificate design resistances shall be determined in accordance with ETAG 001 Annex C.

Note: In some cases, characteristic capacities quoted in manufacturer's data (or given in ETA Certificates) take account of certain influencing factors (e.g. cracked or non-cracked concrete conditions, concrete strength etc). Where this is the case there is no need to take these particular factors into account separately. However, it is important to be satisfied that all relevant influencing factors have been taken into account.

Step 7
Evaluate the design resistance of the metal component in accordance with relevant standards. Where the product has an ETA Certificate valid for the proposed application the design resistance of the metal component may be calculated in accordance with ETAG 001 Annex C using data from the ETA certificate.

Step 8
The shear design resistance ($V_{Rd,uls}$) of the anchor is taken as the lowest design resistance obtained for the various failure modes (including metal component failure). Compare $V_{Rd,uls}$ with $V_{Sd,uls}$.

Step 9
With reference to load/displacement data provided by the manufacturer (or data given in an ETA Certificate valid for the proposed product/application), check that predicted displacement for SLS action under short and long-term loads is acceptable.

Step 10
Evaluate the test load to be applied. An axial test load should be applied to anchorages carrying shear. The axial test load for an anchorage carrying shear should be equal to or greater than the calculated axial design resistance ($N_{Rd,uls}$), but should not exceed 1.1 times the ULS design resistance (i.e. $1.1N_{Rd,uls}$).

Anchorages Subject to Combined Tension and Shear
For anchorages subject to tension and shear, the following expression should be satisfied:

$$\beta_N + \beta_V < 1.2$$

where: $\beta_N = N_{Sd,uls} / N_{Rd,uls}$
$\beta_V = V_{Sd,uls} / V_{Rd,uls}$

4. TYPE OF GROUT

General
Selection of an appropriate grout requires consideration of the environment and conditions to which the anchorage will be exposed during and after installation. Some of the key issues to consider when selecting a product are: health and safety, rate of strength gain, resistance to corrosion, the effect on performance when installation/curing takes place in wet or damp conditions, performance in high and low temperatures (including creep) etc. Some general guidance on these issues is provided in CIRIA Technical Report C537 'The use of epoxy, polyester and similar reactive polymers in construction'(10). Guidance relating specifically to bonded anchors is provided within a series of guidance notes produced by the Construction Fixings Association and in manufacturer's literature.

Fire
Fire is unlikely to be a significant consideration in the design of bonded anchorages in most highway structures. However, in circumstances where the risk of fire is increased, or the implications of anchors failing in a fire situation are severe, the effects of fire should be considered in the development of the design. Specifically, in applications where bonded fixings are exposed to fire, consideration should be given to the implications of reduced resin bond strengths at elevated temperatures. Specialist advice and data should be sought from the product manufacturer. The manufacturer can often provide data relating to the temperature at which bond strength weakens significantly. In a fire situation, the temperature at relatively shallow depths within the concrete will often be much lower than that at the concrete surface. Therefore, in many cases where the primary load effect is axial tension, the effects of fire can be mitigated by increasing the embedment depth to compensate for the loss of bond strength close to the surface of the concrete. It should be noted that in a fire situation metal component failure may be the controlling factor.

Hole Formation
Holes can be formed by percussive drilling or diamond coring. The latter may be necessary in some situations (e.g. where existing fixings are 'over-cored', or there are concerns that the percussive action of the drill may cause damage to the structure). Holes with a rough internal surface (e.g. percussion drilled holes) are often preferred to smooth sided holes as the integrity of the anchorage is less reliant on adhesion. It is recognised that the adhesion characteristics of proprietary grouts is variable. For example, the adhesion characteristics of epoxy resin grouts may be superior to those of polyester equivalents. As such the performance of epoxy resin grouts can be less dependent on mechanical interlock. However, a number of manufacturers of epoxy resin grouts state categorically that roughening the internal surface of diamond drilled holes is essential. The use of diamond cored holes (internally roughened or left smooth) is only permitted as follows:

i) If the proprietary product has a current European Technical Approval for which installation in diamond cored holes is permitted under the terms of the European Technical Approval, or

ii) The manufacture provides evidence that performance data for a particular anchor relates to testing in a diamond cored hole and that performance is not sensitive to workmanship during installation. The supporting evidence should state whether the cored hole was left 'smooth' or internally roughened prior to installation of the anchor. (Note: The provision of supporting evidence does not negate the requirement for tensile testing on site).

Complying with the manufacturer's recommendations in terms of hole preparation (e.g. cleanliness and concrete moisture content) is important for all anchor systems. Note: Roughening holes by acid etching is not permitted.

Performance can be sensitive to hole diameter for some resin grouts. It is therefore particularly important to comply with the manufacturer's recommendations in terms of hole diameter.

Curing of Resin Grout

Curing of resin grouts can occur in two ways; catalytic curing, and curing by direct mixing of components. In catalytic curing products, once initiated, the curing action spreads through the grout to cure material not touched by the catalyst. In other products, typically bulk poured and cartridge injection systems, curing depends on thorough mixing of the components. For cartridge injection systems adequate mixing is usually achieved at the nozzle. For bulk poured systems adequate control of mixing operations on site is vital.

5. TYPE OF FIXING/REINFORCEMENT

For permanent and temporary works, the fixing or reinforcing bar shall be stainless steel unless it is fully encased in concrete. It may also be appropriate in some cases to specify stainless steel for fully encased applications. Advice on this issue can be found in BA84 'Use of Stainless Steel Reinforcement in Highway Structures'[(12)]. It should be noted that where fixings pass through bridgedeck waterproofing careful consideration should be given to ensuring integrity of the waterproofing.

Carbon steel reinforcement should be ribbed to BS4449. Stainless steel reinforcement shall conform to BS6744 with the material designation selected in accordance with the recommendations of BA84. Stainless steel fixings (e.g. threaded bar) should be Grade A4. However, for exposed fixings in aggressive environments (e.g. tunnels) consideration should be given to using stainless steel with a higher level of corrosion resistance. Plain round bars and fixings shall not be used in anchorages subject to axial tensile forces. Care should be taken to ensure appropriate isolation of dissimilar metals.

In certain circumstances, it may be appropriate to specify anchors consisting of internally threaded sockets. These can facilitate rapid replacement of a damaged attachment or bolt.

It is important to follow manufacturer's instructions during installation of proprietary fixings. For example, the torque applied to a nut on a threaded stud should not exceed the value recommended by the manufacturer. The application of excessively high torques could induce substantially greater tension in the fixing than that induced by the design loads.

6. TESTING

The performance of anchors/anchored reinforcement can be very different to that anticipated at design stage. For example, performance may be heavily influenced by workmanship and/or environmental conditions. For this reason, on site tensile tests on a sample of installed anchors/anchored reinforcing bars is required in all cases. Further information is given in Section 3.

7. REINSTATEMENT

It will normally be necessary to remove/cut-back temporary fixings on completion of temporary works and to effect an appropriate concrete repair. However, this may not be appropriate if the temporary fixings are to remain in place for possible re-use in the future. Any proposal to retain temporary fixings shall be discussed with the relevant Unit Bridge Manager.

8. AS-BUILT RECORDS

Details of anchorages for permanent works applications and temporary works applications left in place shall be recorded on as-built drawings. The information recorded on the as-built drawings shall include hole diameter, method of hole formation, embedment depth, grout details, metal component details and design resistance details.

9. SPECIFICATION

Model specifications are given in Annex A for use in works relating to highway structures.

Three model specifications are presented in Annex A. These different specifications are provided to facilitate use without modification depending on the role of the Contractor:

A) Contractor to select the anchor system for prescribed loads
B) Contactor to evaluate loads and design the anchorages

In general, where there is conflict between the requirements of the model specification and manufacturer's recommendations, the model specification takes precedence when more onerous. However, where the manufacturer's product specific recommendations are more conservative, onerous or restrictive than the model specification (e.g. the resin grout must not be used in temperatures below $5^{O}C$), it is imperative that the manufacturer's recommendations are complied with.

10. FURTHER INFORMATION

If you have any questions regarding this document, please contact:

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Queries regarding the application of this document with respect to individual structures should, in the first instance, be raised with the relevant Unit Bridge Manager

11. REFERENCES

1. ETAG 001 – Guideline for European Technical Approval of Metal Anchors for Use in Concrete: Part 1 – Anchors in General

2. ETAG 001 – Guideline for European Technical Approval of Metal Anchors for Use in Concrete: Part 5 – Bonded Anchors

3. ETAG 001 – Guideline for European Technical Approval of Metal Anchors for Use in Concrete: Part 6 – Anchors for Multiple use for Non-structural Applications

4. ETAG 001 – Guideline for European Technical Approval of Metal Anchors for Use in Concrete: Annex A – Details of Tests

5. ETAG 001 – Guideline for European Technical Approval of Metal Anchors for Use in Concrete: Annex B – Admissible Service Conditions

6. ETAG 001 – Guideline for European Technical Approval of Metal Anchors for Use in Concrete: Annex C – Design Methods for Anchorages

7. Use of Anchors with European Technical Approvals. UK Guidance – Distinction between Cracked and Non-cracked Concrete (BBA Publication)

8. BS 5080-1: 1993 – Methods of Test for Structural Fixings in Concrete and Masonry: Part 1 – Method of Test for Tensile Loading

9. BS 5080-2: 1986 – Methods of Test for Structural Fixings in Concrete and Masonry: Part 2 – Method for Determination of Resistance to Loading in Shear.

10. The Use of Epoxy, Polyester and Similar Reactive Polymers in Construction – Volume 1: The Materials and their Practical Applications (CIRIA Publication C537)

11. BD 37 – Loads for Highway Bridges.

12. BA 84 – Use of Stainless Steel Reinforcement in Highway Structures.

13. BS EN 1504 Part 6 - Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity – Part 6: Anchoring of reinforcing steel bar.

14. EOTA Technical Report TR023 – Assessment of post-installed rebar connections.

TRANSPORT SCOTLAND

ANNEX A

Three model specifications are presented in this Annex. The appropriate model specification depends on the role of the Contractor:

A. Contractor to select the anchor system for prescribed loads.
B. Contactor to evaluate loads and design the anchorages.
C. Anchorages fully designed in advance.

Model Specification A: Model Specification (AR Specification Clause for the Anchorage of Reinforcement or Fixings) for use when the Contractor is required to select the anchor system for prescribed loads.

A1 Materials

A1.1 Proprietary grout materials shall be supplied by a manufacturer who either:-

(a) Holds a current BSI Certificate of Registration as a BSI Registered Firm of Assessed Capability in accordance with BS EN ISO 9001 : 2000; or

(b) Operates quality assurance procedures of a similar standard to (a) above and which meet the approval of the Overseeing Organisation

A1.2 Resin grout shall be non-expansive, suitable for the proposed inclination of the hole and shall be approved by the Overseeing Organisation. The resin grout shall be stable in the cured condition over the temperature range of -31^{O} to +60^{O}C and be resistant to mechanical and chemical degradation under normal service conditions in a highway environment. In the absence of application specific requirements specified by the Overseeing Organisation, the resin grout shall have an indicative working life of at least 50 years.

A1.3 Cementitious grout shall be a proprietary shrinkage compensated grout, suitable for the proposed inclination of the hole and approved by the Overseeing Organisation. Cementitious grout shall consist only of Portland cement (CEM I) complying with BS EN 197-1, fillers, admixtures approved by the Overseeing Organisation and water complying with BS EN 1008. Cementitious grouts shall not contain a chloride ion content of more than 0.1% by mass of cement.

A1.4 Grout materials shall be stored, mixed, incorporated in the works and cured strictly in accordance with the manufacturer's recommended methods and working procedures.

A1.5 Anchored carbon steel reinforcement of the specified grade shall conform to BS4449. Anchored stainless steel reinforcement of the specified form, material designation and strength shall conform to BS6744. Anchored fixings shall be Grade A4 stainless steel.

A2 Design

A2.1 The Contractor shall select a proprietary grout and metal component (except where the metal component has been specified in advance) for which:

i) the design resistances (calculated in accordance with TS IA 26) exceed the specified design actions,

ii) the requirements of TS IA 26 in relation to combined tension and shear effects are complied with, and
iii) the predicted displacements under serviceability limit state loads (calculated in accordance with TS IA 26) are less than the specified limits.

In verifying compliance with the above, the Contractor should take account of:

- *the classification of the application (safety critical or non-safety critical)*
- *the classification of the concrete (cracked or non-cracked)*
- *the minimum and maximum concrete temperatures*
- *the characteristic concrete cube strength*
- *any application specific criteria relating to embedment depth, such as a maximum embedment depth, or a pre-determined embedment length.*

A3 Installation

A3.1 The holes to receive the reinforcement/fixings shall be set out in accordance with the contract requirements.

A3.2 The locations of the holes shall be checked using a reinforcement detection device to ensure that the position is clear of reinforcement before drilling is undertaken. The action to take when existing reinforcement obstructs the proposed location of a hole shall be agreed with the Overseeing Organisation.

A3.3 Before and after drilling holes the Contractor shall ensure that the existing concrete is sound, and that any significant defects such as fractures, cracks and voids in the vicinity of the hole are brought to the attention of the Overseeing Organisation. Any defective holes shall be re-drilled in new locations to be agreed with the Overseeing Organisation.

A3.4 Holes shall be formed in accordance with the manufacturer's instructions using a rotary percussive drill. Diamond cored holes (internally roughened or left smooth) shall only be permitted as follows:

i) If the proprietary product has a current European Technical Approval for which installation in diamond cored holes is permitted under the terms of the European Technical Approval, or

ii) The manufacture provides the Overseeing Organisation with evidence that performance data for a particular anchor relates to testing in a diamond cored hole and that performance is not sensitive to workmanship during installation. The supporting evidence should state whether the cored hole was left 'smooth' or internally roughened prior to installation of the anchor.

Roughening the internal surface of the hole by acid etching is not permitted. The diameter of the drilled holes shall be in accordance with manufacturer's requirements. The embedment depth shall not be less than that required by the design and any minimum specified on the contract drawings. In no case shall the minimum embedment length be less than 100mm.

A3.5 For resin based grout, the condition of the drilled holes (cleanliness and concrete moisture content) shall be in accordance with the manufacturer's instructions before inserting any resin.

A3.6 Resin based grout shall only be installed at temperatures within the range permitted in the manufacturer's instructions.

A3.7 For cementitious grout, the holes shall be clean, free of contaminants and kept damp for a minimum of 2 hours prior to grouting. There shall be no standing water in the hole at the time of grouting.

A3.8 Grouting with cementitious grout shall not take place when the ambient temperature falls below 5 ^{O}C or when the temperature of the substrate concrete falls below 2 ^{O}C. Artificial methods of heating may be utilised subject to the approval of the Overseeing Organisation. Cementitious grout shall be mixed to produce a homogeneous grout. When mixed cementitious grout shall be of an appropriate consistency for the method of grout installation and capable of filling the drilled hole without the need for vibration. The grout shall not bleed or segregate. The temperature of freshly mixed cementitious grout shall be within the range 5 ^{O}C to 30 ^{O}C.

A3.9 The Contractor shall ensure that the grout fills the hole entirely without air voids following insertion of the reinforcing bar/fixing and that the reinforcing bar/fixing is fully coated by the grout. Excess grout shall be removed immediately.

A3.10 The reinforcing bars/fixings shall be free of rust/contamination that may affect the anchorage bond.

A3.11 The Contractor shall not insert reinforcing bars/fixings into resin based grout after the gel time (referred to as 'open time' in ETAG 001), and shall not disturb the completed installation until the grout is fully cured.

A4 Testing

A4.1 Axial load testing in accordance with BS 5080 Part 1 - Structural Fixings in Concrete and Masonry shall be carried out. The requirement in Clause 6 of BS5080 Part 1 for the reaction of the loading frame to be at least 8A from the axis of the fixing does not apply for embedment depths in excess of 200mm. The number of tests to be carried out shall be as specified by the Overseeing Organisation.

A4.2 Cementitious grout anchorages shall not be tested within 5 days of installation.

A4.3 The location of the test anchorages shall be as directed by the Overseeing Organisation.

A4.4 The test load shall be taken as the greater of the following:

i) Any test load specified by the Overseeing Organisation
ii) For anchorages subject to shear loads, the test load derived in accordance with Section 3 of TS IA 26 for anchorages subject to shear forces.

A4.5 Each tested reinforcing bar/fixing shall be loaded incrementally in tension in accordance with BS 5080 Part 1: 1993 up to the test load. The number of load increments shall not be less than 10.

A4.6 Incremental loads shall be held for not less than 30 seconds and the test load for not less than 5 minutes.

A4.7 Readings shall be taken immediately after applying load and at the ends of the time intervals stated above.

A4.8 The total movement of the anchored reinforcing bar/fixing, less the calculated elongation of the bar/fixing during the test (based on the length of bar/fixing between the concrete surface and the point of load application), shall not exceed 5% of the nominal diameter of the bar/fixing.

A4.9 Any evidence of slip during loading up to the test load, as demonstrated by a significant change in the slope of the load/extension curve, shall constitute a failure.

A4.10 If the failure load of any of the tested bars/fixings is less than the required test load then, the testing frequency shall be increased and remedial actions, such as increasing the number of anchorages or the embedment depth shall be proposed for consideration by the Overseeing Organisation.

A4.11 The Overseeing Organisation shall be provided with the results of the pullout tests. The results for each test shall include a graph of load/extension.

Model Specification B: Model Specification (AR Specification Clause for the Anchorage of Reinforcement or Fixings) for use when the Contractor is required to evaluate loads and design the anchorages.

B1 Materials

B1.1 Proprietary grout materials shall be supplied by a manufacturer who either:-

(a) Holds a current BSI Certificate of Registration as a BSI Registered Firm of Assessed Capability in accordance with BS EN ISO 9001 : 2000; or

(b) Operates quality assurance procedures of a similar standard to above and which meet the approval of the Overseeing Organisation

B1.2 Resin grout shall be non-expansive, suitable for the proposed inclination of the hole and shall be approved by the Overseeing Organisation. The resin grout shall be stable in the cured condition over the temperature range of -31^{O} to +60^{O}C and be resistant to mechanical and chemical degradation under normal service conditions in a highway environment. In the absence of application specific requirements specified by the Overseeing Organisation, the resin grout shall have an indicative working life of at least 50 years.

B1.3 Cementitious grout shall be a proprietary shrinkage compensated grout, suitable for the proposed inclination of the hole and approved by the Overseeing Organisation. Cementitious grout shall consist only of Portland cement (CEM I) complying with BS EN 197-1, fillers, admixtures approved by the Overseeing Organisation and water complying with BS EN 1008. Cementitious grouts shall not contain a chloride ion content of more than 0.1% by mass of cement.

B1.4 Grout materials shall be stored, mixed, incorporated in the works and cured strictly in accordance with the manufacturer's recommended methods and working procedures.

B1.5 Anchored carbon steel reinforcement shall conform to BS4449
Anchored stainless steel reinforcement shall conform to BS6744.
Anchored fixings shall be Grade A4 stainless steel.

B2 Design

B2.1 The anchorages shall be designed and the test load calculated in accordance with TS IA 26. The design shall include a check on displacement under serviceability limit state actions.

B3 Installation

B3.1 The holes to receive the reinforcement/fixings shall be set out in accordance with the requirements of the design.

B3.2 The locations of the holes shall be checked using a reinforcement detection device to ensure that the position is clear of reinforcement before drilling is undertaken. The *action to take when existing reinforcement obstructs the proposed location of a hole shall be agreed with the designer and the Overseeing Organisation.*

B3.3 Before and after drilling holes the Contractor shall ensure that the existing concrete is sound, and that any significant defects such as fractures, cracks and voids in the vicinity of the hole are brought to the attention of the designer and the Overseeing Organisation. Any defective holes shall be re-drilled in new locations to be agreed with the designer and the Overseeing Organisation.

B3.4 Holes shall be formed in accordance with the manufacturer's instructions using a rotary percussive drill. Diamond cored holes (internally roughened or left smooth) shall only be permitted as follows:

i) If the proprietary product has a current European Technical Approval for which installation in diamond cored holes is permitted under the terms of the European Technical Approval, or

ii) The manufacture provides the Overseeing Organisation with evidence that performance data for a particular anchor relates to testing in a diamond cored hole and that performance is not sensitive to workmanship during installation. The supporting evidence should state whether the cored hole was left 'smooth' or internally roughened prior to installation of the anchor.

Roughening the internal surface of the hole by acid etching is not permitted. The diameter of the drilled holes shall be in accordance with manufacturer's requirements. The embedment depth shall not be less than that required by the design and any minimum specified on the design drawings. In no case shall the minimum embedment length be less than 100mm.

B3.5 For resin based grout, the condition of the drilled holes (cleanliness and concrete moisture content) shall be in accordance with the manufacturer's instructions before inserting any resin.

B3.6 Resin based grout shall only be installed at temperatures within the range permitted in the manufacturer's instructions.

B3.7 For cementitious grout, the holes shall be clean, free of contaminants and kept damp for a minimum of 2 hours prior to grouting. There shall be no standing water in the hole at the time of grouting.

B3.8 Grouting with cementitious grout shall not take place when the ambient temperature falls below 5 ^{O}C or when the temperature of the substrate concrete falls below 2 ^{O}C. Artificial methods of heating may be utilised subject to the approval of the Overseeing Organisation. Cementitious grout shall be mixed to produce a homogeneous grout. When mixed cementitious grout shall be of an appropriate consistency for the method of grout installation and capable of filling the drilled hole without the need for vibration. The grout shall not bleed or segregate. The temperature of freshly mixed cementitious grout shall be within the range 5 ^{O}C to 30 ^{O}C.

B3.9 The Contractor shall ensure that the grout fills the hole entirely without air voids following insertion of the reinforcing bar/fixing and that the reinforcing bar/fixing is fully coated by the grout. Excess grout shall be removed immediately.

B3.10 The reinforcing bars/fixings shall be free of rust/contamination that may affect the anchorage bond.

B3.11 The Contractor shall not insert reinforcing bars/fixings into resin based grout after the gel time (referred to as 'open time' in ETAG 001), and shall not disturb the completed installation until the grout is fully cured.

B4 Testing

B4.1 Axial load testing in accordance with BS 5080 Part 1 - Structural Fixings in Concrete and Masonry shall be carried out. The requirement in Clause 6 of BS5080 Part 1 for the reaction of the loading frame to be at least 8A from the axis of the fixing does not apply for embedment depths in excess of 200mm. The number of tests to be carried out on works anchorages (or sacrificial anchorages) shall be a minimum of 10% (3% for non-safety critical applications) of the total number of anchorages proposed in the works, subject to a minimum of 3 for each size and type of anchorage.

B4.2 Cementitious grout anchorages shall not be tested within 5 days of installation.

B4.3 The location of the test anchorages shall be as directed by the designer and agreed with the Overseeing Organisation.

B4.4 Each tested reinforcing bar/fixing shall be loaded incrementally in tension in accordance with BS 5080 Part 1: 1993 up to the test load. The number of load increments shall not be less than 10.

B4.5 Incremental loads shall be held for not less than 30 seconds and the test load for not less than 5 minutes.

B4.6 Readings shall be taken immediately after applying load and at the ends of the time intervals stated above.

B4.7 The total movement of the anchored reinforcing bar/fixing, less the calculated elongation of the bar/fixing during the test (based on the length of bar/fixing between the concrete surface and the point of load application), shall not exceed 5% of the nominal diameter of the bar/fixing.

B4.8 Any evidence of slip during loading up to the test load, as demonstrated by a significant change in the slope of the load/extension curve, shall constitute a failure.

B4.9 If the failure load of any of the tested bars/fixings is less than the test load the testing frequency shall be increased and remedial actions, such as increasing the number of anchorages or the embedment depth shall be proposed for consideration by the Overseeing Organisation.

B4.10 The Overseeing Organisation shall be provided with the results of the pullout tests. The results for each test shall include a graph of load/extension.