CONSTRUCTION FIXINGS association

CI/Sfb Xt6

December 1995

CFA Guidance note:
Anchor Selection

CONTENTS

1 INTRODUCTION

This Guidance note is intended to provide an introduction to the factors which need to be taken into account when selecting an anchor for any load bearing or safety critical application. While selection criteria apply to all fixing types only metal and bonded anchors are considered in detail, light duty fixings are covered in another Guidance note [1].

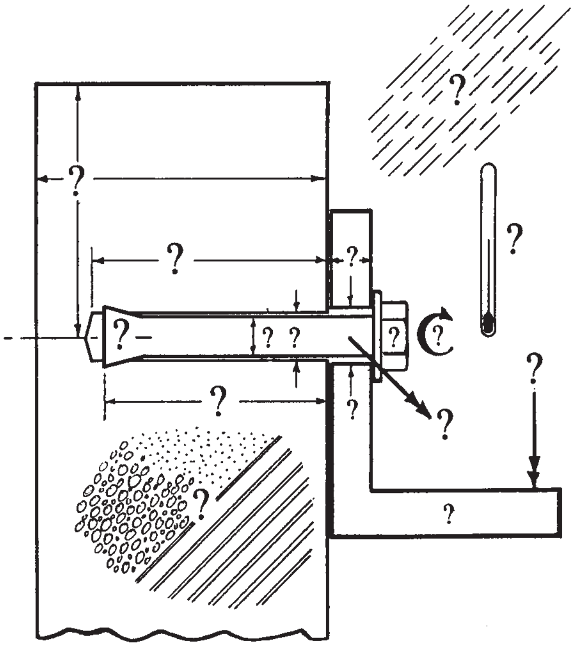
The implications of poor anchor selection can range from the inconvenience of site delays while incorrect specifications are corrected, to potential disaster in the case of inadequate structural connections. The wrong finish may lead to long term corrosion; undersized anchors may fail causing damage or injury; over sized anchors may themselves cause structural problems. An anchor which works well in concrete may be ineffective in weaker materials. One type of anchor may be well suited to an application but another, equally as good from all other aspects, may be easier and cheaper to install. The common consequence of poor selection is added cost.

All members of the **Construction Fixings Association** offer technical advice to help with this selection process. In the case of safety critical applications it is wise to seek their recommendations or their endorsement of your selection. For details of **Association** members see [2].

Whether selecting anchors yourself or using the manufacturer's advice service, familiarisation with the factors set out below will help you get the most appropriate anchor for your application.

Practical advice is offered on the basis of best current practice within the industry. The Association accepts no liability for any consequences of this advice being followed.

2 SELECTION PROCESS



Some factors to be considered in anchor selection

There are three key stages in selecting any fixing: **Type, Size and Finish.** They should, initially, be considered in that order. Constraints within each stage may require reconsideration of an earlier one. In some instances doubts over the strength of the base material may require exploratory tests on site before final selection can be confirmed. Realisation of the specification is only achieved if the specified fixing is correctly installed. All these subjects are referred to in the following sections.

Which TYPE of fixing?
Suitability for base material
Concrete, masonry (brick, block, stone)
Practical considerations
Attachment configuration
Temperature

Which SIZE of fixing?
Applied load
Recommended loads, direction, effect of close edge and centre spacings, increased embedment depth, static/dynamic loads.
Fixture thickness

Which FINISH?
Corrosion
Oxidation, galvanic corrosion, stress corrosion, chemical corrosion.

3 WHICH TYPE OF FIXING?

3.1 SUITABILITY FOR BASE MATERIAL

Key factors - suitability & strength, structural thickness. *Fixings designed for concrete may not work in weaker materials; normally the stronger the base material the stronger the fixing; structural thickness must be adequate to support the applied load and expansion stresses from the fixing.*

CONCRETE

Concrete is the material into which most structural connections are made, for which most anchors are designed and performance is most frequently quoted.

Performance is most commonly quoted for C20/25 concrete which has a mean compressive strength of 30N/mm^2. Some manufacturers also quote tensile performance in stronger grades or allow the calculation of increased tensile allowable loads within certain limits. Exceptionally strong concrete, i.e. > 60N/mm^2, may inhibit the expansion of some expanding anchors, check with the manufacturer for suitability. The same criteria apply to in-situ and pre-cast concrete; the slimmer sections and higher strengths of pre-cast units may mean a different anchor choice.

Cracked/uncracked concrete

Anchors of all attachment configurations and types are available for use in cracked concrete.

It is acknowledged that concrete may be cracked for a variety of reasons, primarily the loading of the structure, (cracked concrete in tension zones, uncracked in compression zones) and reinforcement helps limit crack widths and restrict crack propagation. Although there is no evidence to hand in the UK of anchor failures being caused by cracked concrete, the "ETAG" (Guideline for European Technical Approval of Metal anchors for use in concrete) [3] allows for the approval of anchors for use in both cracked or uncracked concrete or for use only in uncracked concrete. Anchors are now available, using both traditional and new design concepts, which function well in cracked concrete. As well as the new "Undercut" anchors both expansion and resin bonded anchors are available approved for cracked concrete. Expansion anchors not specifically designed for use in cracked concrete may, with care, be considered for such applications by locating the expansion point in the compression zone, seek manufacturer's advice.

Reinforcement

Rebar should be considered at the design stage.

Reinforcement does not improve anchor performance and while theoretically it may allow setting closer to edges this is difficult to assess and is best ignored. Performance is usually quoted for unreinforced concrete. If rebar is hit during drilling and may not be cut then the aborted hole should be filled with a strong, non-shrink grout and the new hole spaced at least the depth of the aborted hole away. Additional holes designed into brackets will help cater for this common eventuality. (For more details see[4])

MASONRY - brick, block and stone.

Common factors - range of compressive strengths, unknown mortar strength, fixing location within unit and wall, voids.

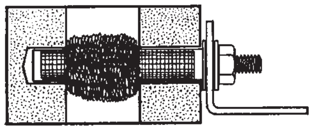
Choose anchors which will not crack weak materials, avoid fixing into joints if possible, locate away from the edges of walls or individual bricks and blocks, use resin systems for voids. Use site tests to check loads.

Brickwork [5]

Probably the most awkward material to fix into.

Strengths vary from 5 - 70N/mm^2, mortar may be weak or non-existent in parts of the joints, bricks may be solid or have frogs or perforations which may not be filled with mortar.

Bonded anchors[6] are particularly suitable as they exert no expansion stresses and will fill small voids, while injection resin systems have accessories available for controlling resin in frogs, poorly filled joints and perforations. The most appropriate metal anchors are thin-walled sleeve anchors which exert low expansion stresses and are less likely to crack weak bricks than anchors with thick expanders. They can also work well in perforated bricks. Shield anchors up to medium sizes work well in reasonably strong brickwork with good mortar joints. Nylon fixings are also often suitable for brickwork.



Injection resin with mesh sleeve in perforated brick

Fixing Location - careful positioning avoids problems.

Design fixing locations for expansion anchors on the horizontal brick centre line (to avoid frogs) away from ends of bricks, at least a brick length from the wall edge and well below the top of an unrestrained wall. Do not locate in joints. These guidelines may be slightly relaxed for resin bonded anchors. Choose length to avoid expansion close to back of brick and to ensure drilling does not break through.

Blockwork [7]

Includes the lowest strength solid substrate!

Few metal expansion anchors work satisfactorily in "thermal" blocks. Thin walled sleeve anchors may be considered for solid blocks when the compressive strength of the blocks is known to be above 10N/mm^2. Metal and nylon anchors specially developed for aerated concrete work well as do injection resin systems for which accessories are available for hollow blocks. Note comments on torques in section 6 page 5. Similar guidelines for positioning apply as for bricks.

Stonework

Similar approach to brickwork.

Strengths as variable as bricks (weak sandstone to granite). An added complication is the variation in shapes and sizes within the same wall and the possibility of rubble infill within "solid" stone walls. Product suitability and location guidelines generally as for brickwork.

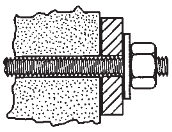
3. 2 PRACTICAL CONSIDERATIONS

Practical aspects include the diameter of predrilled holes in the fixture, which may limit anchor size; the need for immediacy of fixing and the attachment configuration of the fixture to the fixing. The latter can be divided into 4 categories as illustrated below.

ATTACHMENT CONFIGURATION

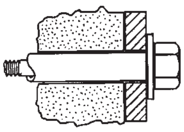
Four attachment configurations are defined as these affect the practicality of using each anchor. These categories are used in the selection table on page 7.

Through Stud



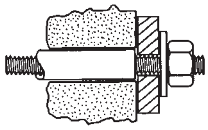
Hole in base material equals nominal bolt diameter so fixing may be installed through fixture .

Through Sleeve



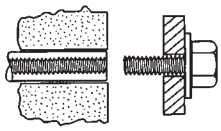
Through fixing with increased shear strength. May have projecting thread or bolt head.

Projecting Stud



The fixture is positioned over the installed fixing before tightening. Care is needed on attachment of the fixture to protect the thread.

Internal Thread



Accepts a threaded rod, ideal for suspension of services, or a bolt. This enables the fixture to be manoeuvred into place over the fixing, e.g. fixing heavy objects to floors.

TEMPERATURE

Service temperatures

All metal and bonded anchors supplied by members of the Association are suitable for use in normal ambient temperatures. Where a fire rating in excess of half an hour is required ALL anchors, including all-metal anchors, will require additional fire protection to maintain full performance. This should be added in an area around the fixing which protects the surrounding base material to a radius at least equal to the fixing's embedment depth. Some manufacturers can provide information on fire ratings for unprotected fixings for exposure to fire for up to 120 minutes with reduced loading capacity. Bonded anchors are usually suitable for ambient temperatures up to 80°C above which they will start to lose strength. This may be compensated for by deeper embedment, seek the manufacturer's advice. Most metal anchors may be specified for in service temperatures down to –40°C. Check with manufacturer for plastic fixings.

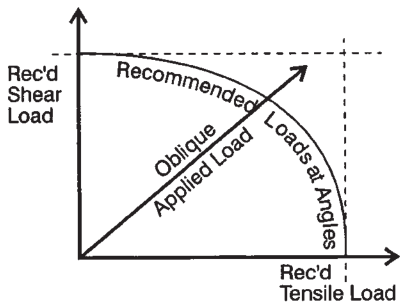
Installation temperatures
Resin bonded anchors are limited to a range of, typically, between –5° and +40°C while cementitious anchors may not be installed below + 5°C. Metal anchors have no similar restrictions.

4 WHICH SIZE OF FIXING?

4.1 APPLIED LOAD

RECOMMENDED LOADS
Members of the **Construction Fixings Association** set recommended loads as a result of exhaustive tests, usually to a recognised test procedure or as part of an approval programme. Recommended loads are commonly derived from characteristic loads subject to a safety factor. Future ETA's[10] (European Technical Approvals) carried out to the ETAG will quote characteristic loads to be used with partial safety factors.

Direction
It is self evident that applied loads must be less than the manufacturer's recommended load for the direction concerned, tension or shear. However for oblique or combined loads a check must also be carried out to ensure that the resolved components must be less than the recommended tensile and shear loads without exceeding the capacity in the direction concerned.



Oblique load exceeds capacity while resolved components are less than Recommended Loads

Manufacturers use different techniques to ensure that this capacity is not exceeded, check with them.

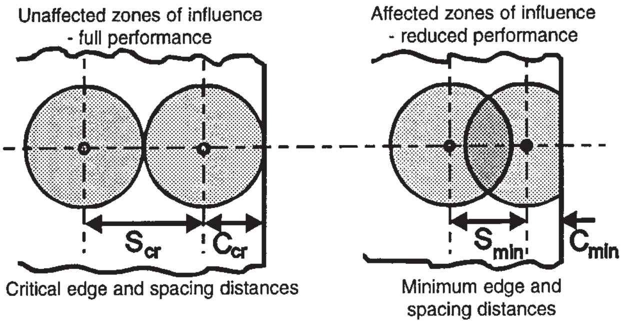
Some anchors are noticeably stronger in shear than in tension e.g. thick walled sleeve anchors, while resin bonded stud anchors are usually stronger in tension than shear.

Effect of close edge and centre spacing

> ***All fixings need structural material around them to support the transmitted load.***

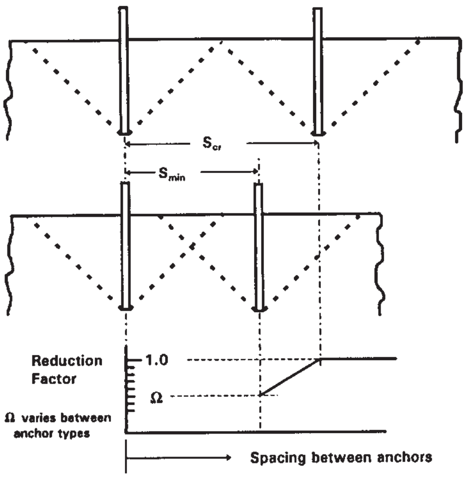
The simplest approach is to consider the zone of influence caused by compression stresses around expansion anchors. Although more complex than shown below, it can be understood that there are limits to both edge distances and spacings between anchor centres. The closest dimensions at which full performance may be used are defined as "Critical" edge distance (C_{cr}) and centre spacing (S_{cr}). While "Minimum" dimensions (C_{min} and S_{min}) are the absolute minimum distances at which anchors may still be used but with reduced performance.

Zones of influence



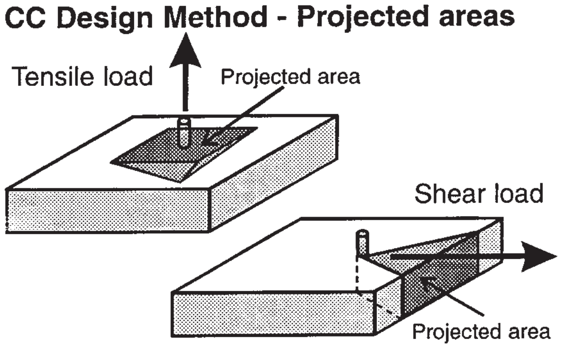
Most anchor types conform to this approach but some displacement controlled anchors may not be used at edges closer than the critical edge distance because of the high stresses induced in the base material during their setting .
A common approach for anchor selection is to use reduction factors for distances between critical and minimum distances as illustrated below for anchor spacing, an identical approach is used for edge distances. This enables allowable loads to be calculated for complex applications, see Section 8, "Worked Example".

Reduction factor approach for anchor spacing



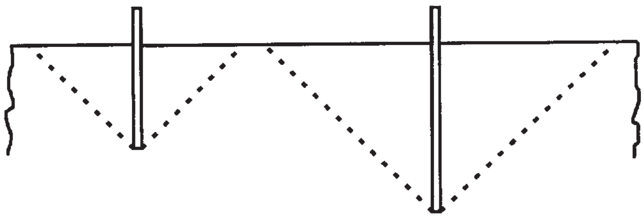
An alternative design approach (as used in the ETAG) called the Concrete Capacity (CC) method relates performance to the projected area of a pyramid whose height is the effective embedment of the anchor. Any reduction in this projected area due to close edges reduces the anchor performance. Groups of fixings are considered to have the performance derived from considering the projected area of the group. See [10].

CC Design Method - Projected areas



Effect of increased embedment depth
Recommended loads for most fixings are quoted at the maximum fixture thickness which relates to the minimum embedment depth. In many cases performance will increase as embedment depth increases until the mode of failure changes e.g. from concrete cone failure to steel failure.

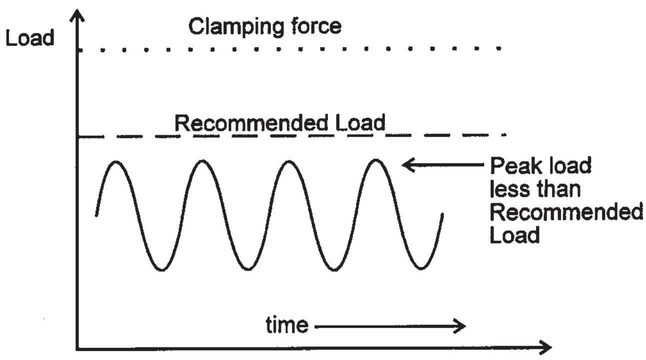
Deeper embedment for improved performance



Some manufacturers quote performance at alternative embedment depths while others allow the upward adjustment of allowable loads for deeper embedments by calculation as long as stress limits on the bolt material are not exceeded.

Nature - static and dynamic loads
Recommended and approved loads are generally quoted only for static applications. Where loads are dynamic in nature extra consideration must be given.

Relation between Dynamic and Recommended loads



In applications where the fixture is clamped down by the tightening of the fixing to an installation torque recommended by the manufacturer then the induced clamping force will usually exceed the manufacturer's recommended load by a significant margin. This means the fixing may not move. For a dynamic load where the peak load is known to be less than the recommended load, and therefore less than the clamping force, the fixing will effectively be unaware of the variation in loading and the anchor may be safely specified.

For shock loads check with the manufacturer.

4.2 FIXTURE THICKNESS

Anchors which are supplied complete have a limited fixture thickness. Hole depths are often quoted for the maximum fixture so when thinner fixtures are used the hole depth must be increased accordingly. For anchors supplied without bolts take account of the correct engagement within the anchor when specifying bolt length.

5 WHICH FINISH?

5. 1 CORROSION[8]

OXIDATION

Depending on the conditions and required life, normal rusting may be avoided by specifying protective coatings or stainless steel. For dry internal applications zinc plated carbon steel fixings are suitable, for short and medium term external uses hot dipped galvanised carbon steel may be considered. For long term external exposure stainless steel should be specified, Grade A2 for normal unpolluted areas, Grade A4 for polluted areas. The table below shows the relative durability of a variety of finishes and materials in a selection of exposure conditions.

Relative durability of finishes in different exposure conditions S, M, L = Short, Medium, Long term ✱ = depends on conditions ✗ = Not suitable	Zinc plated steel	Hot dip galvanised	Stainless Grade A2	Stainless Grade A4	Special alloys
Internal Dry	L	L	L	L	
Internal Humid	S	M	L	L	
External Non-polluted	S	M	L	L	
External Polluted	✗	S	M	L	
Coastal	✗	S	M	L	
Marine Splash-zone	✗	✗	S	M	
Special conditions	✗	✗	✗	✱	✱

BI-METALLIC (GALVANIC) CORROSION

Contact between dissimilar metals in the presence of an electrolyte, including rain water, should be avoided as the rate of corrosion may be accelerated depending on the particular metals in contact and their relative areas. For instance when zinc plated steel components are fixed with stainless steel fixings the increased corrosion of the plated steel part will be minor due to its relatively larger area. Otherwise dissimilar metals should be isolated using suitable washers or protected from the electrolyte.

CHEMICAL OR SEVERE CORROSION

In areas subject to high atmospheric pollution or marine environments even Grade A4 Stainless steel may have a reduced life expectancy. Special alloys are now available with increased resistance. Refer to the manufacturer for advice in applications where fixings are exposed to particular chemicals.

STRESS CORROSION

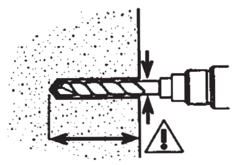
Stress corrosion occurs in conditions where elevated temperatures coincide with moisture and the presence of chlorides, as for instance in swimming pool roofs. Normal materials, including A4 stainless, are not suitable and special measures must be taken including the consideration of special alloys.

6 INSTALLATION FACTORS [4]

Ensure installers follow manufacturer's instructions

Awareness of installation requirements helps specifiers ensure designed performance is met. Some key points are highlighted below.

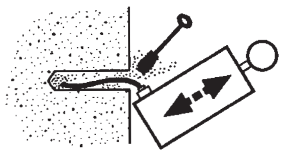
Drill hole to correct diameter and depth



Diameter is important for all anchors. A few types may be set in holes deeper than the minimum while others are set against the bottom of the hole. For some anchors adjust hole depth for fixture thickness.

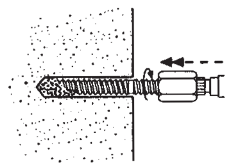
(For through fixings, holes in fixture should be +1mm on nominal drill diameter.)

Clean hole thoroughly



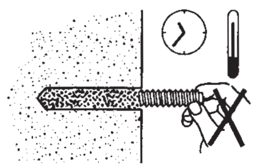
Important for all anchors but particularly resin bonded (and especially injection) types for which brushing and blowing is recommended.

Use correct setting equipment and procedure



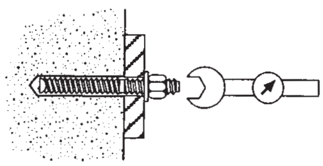
Applies particularly to deformation controlled, undercut and bonded anchors.

Bonded anchors - allow curing time



Curing time is temperature dependent .

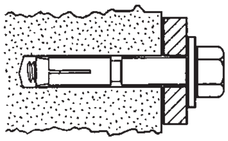
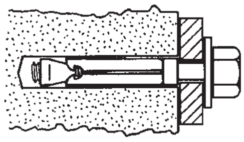
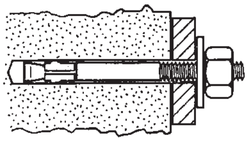
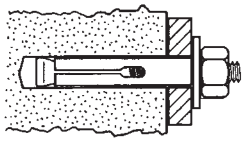
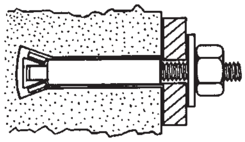
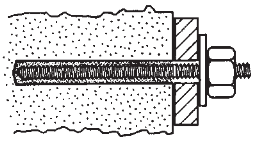
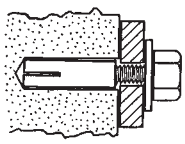
Tighten to correct torque



Manufacturers' recommended torques usually protect the bolt material from being over stressed while inducing a tension in the bolt, and corresponding clamping force through the fixture, in excess of the recommended tensile load. This means the fixture will not move. Recommended torques are therefore worth insisting on. In bonded anchors they also protect the bond from being over stressed so in weak base materials, where the bond will be weak, it may be necessary to reduce the torque from that quoted for concrete in proportion to the reduction in recommended load.

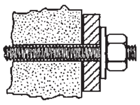
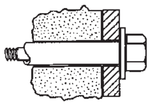
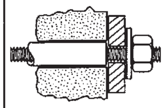
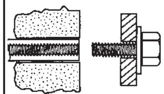
CFA Guidance note:
Anchor Selection

The table below shows a selection of parameters for the major types of anchors available for load bearing applications.

7 SUITABILITY AND APPLICATION PARAMETERS	**Base material suitability**							
		Brick		**Block**				
Anchor type	**Concrete**	Solid	Perforated	Dense Aggregate	Light Aggregate - Solid	Light Aggregate - Hollow	Aerated	**Stone**
Thick-walled sleeve (Torque controlled expansion) Tightening the nut or bolt draws the cone into the sleeve causing it to expand. A crush feature is usually incorporated to pull down any gap between fixture and concrete. Available in stud or bolt configurations. Usually strong in both tension and shear. 	●							
Shield (Torque controlled expansion) Tightening the nut or bolt draws the cone into the sleeve causing it to expand. Shield finishes flush with base material. Large expansion ratio gives tolerance to hole dimensions which powerful drilling may open up oversized in weaker substrates. Available in projecting stud, loose bolt, shield only, hook and eyebolt versions. 	●	❍	❍	❍				❍
Through bolt (Torque controlled expansion) Tightening the nut draws the tapered end of the bolt into a metal collar causing it to expand. Hole diameter in base material same as nominal bolt diameter. Gaps between fixture and base material automatically pulled down. Available with alternative embedment depths. 	●							
Thin-walled sleeve (Torque controlled expansion) Expansion of the sleeve achieved by turning the nut and drawing the tapered end of the bolt into the sleeve. The thinner material of the sleeve means lower expansion forces which protects weaker base materials from cracking or crushing. A weak point in the sleeve ensures the clamping force is exerted through the fixture. 	●	●	❍	●	❍			●
Undercut A strong mechanical interlock is formed in the base material, without expansion stresses, by segments which are made to open into the undercut shape either by turning the nut to draw the tapered cone into the segments or by driving the sleeve over a tapered cone. The undercut may be made by a special drilling system or by the anchor itself. 	●							●
Bonded anchor - stud or socket The anchor is bonded into the base material by a cementitious or more commonly a 2 part resin grout which may be introduced either in a capsule or from an injection cartridge with special mixing nozzle. Lack of expansion stresses allows closer edge distances, centre spacings and structural thickness than expansion anchors. 	●	●	❍	●	●	❍	❍	●
Deformation controlled socket Expansion is achieved by driving a plug down the centre of the internally tapered sleeve using a special shouldered dowel punch which controls the displacement and hence the expansion. High stresses induced in base material on setting. 	●							

Suitability ratings ● = suitable, ❍ = limited suitability.

It is necessarily very generalised. There are many variants on most types and other anchoring principles available.

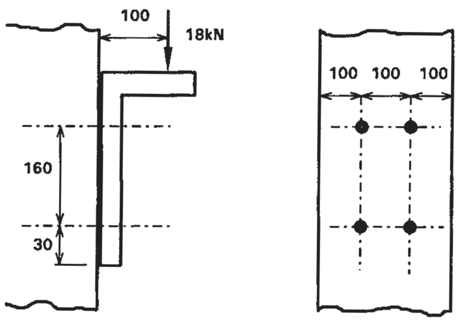
Attachment configuration									
Through Stud 	**Through Sleeve** 	**Projecting Stud** 	**Internal Thread** 	**Duty ***	**Some approved for Cracked Concrete**	**Available in Stainless Steel**	**May be loaded immediately**	**Set independent of fixture**	**Anchor type**
	✓			**H**	✓	✓	✓		**Thick-walled sleeve**
		✓	✓	**M**		✓	✓		**Shield**
✓				**M**	✓	✓	✓		**Through bolt**
	✓			**L**		✓	✓		**Thin-walled sleeve**
✓	✓	✓	✓	**M-H**	✓	✓	✓	✓	**Undercut**
		✓	✓	**H** stud	✓	✓		✓	**Bonded anchor**
			✓	**M**		✓	✓	✓	**Deformation controlled**

* Duty in concrete: L = light: M = medium; H = heavy, due to overlaps in performance these assessments are relative.

8 WORKED EXAMPLE

This example is included simply to illustrate a typical selection process using the Reduction Factor technique of section 4.1. The approach of actual manufacturers may vary from that shown.

Illustration for worked example



Concrete strength is > 45 N/mm² and is considered to be uncracked. The bracket is subject to coastal exposure.

To avoid confusion on site the same anchor is required for top and bottom fixings. A through fixing is preferred.

The following abbreviations are used:

- N_{sd} & V_{sd} - Design (Applied) tensile and shear loads
- N_{rec} & V_{rec} - Recommended tensile and shear loads
- N_{rec}' & V_{rec}' - Recommended loads after modification by influencing factors

Design loads
Taking moments about the foot of the bracket and ignoring the capacity of the lower fixings gives a tensile load per top bolt of

N_{sd} = 4.7kN per bolt

Shear loads assumed equivalent to the applied load shared equally by all bolts.

V_{sd} = 4.5kN

Anchor specification
Anchor considered is a Thick-walled sleeve anchor suitable for through fixing, M 12 diameter,

N_{rec} = 18 kN (30N/mm² concrete)
V_{rec} = 22.8kN

This manufacturer allows N_{rec} to be increased, due to higher concrete strength, using the formula:

$N_{rec(45)} = Nrec(30) \times \sqrt{(\text{Actual strength} \div 30)}$
i.e. $N_{rec(45)}$ = 22.0kN

Bolt stress = 260 N/mm², O.K. for Grade A4.70

Spacing and Edge criteria published by the manufacturer are S_{cr} = 200mm, S_{min} = 100mm
C_{cr} = 160mm, C_{min} = 75mm, (Tension), 85mm (Shear)

Reduction factors	Tensile	Shear
Edge distance of 100mm,	.75	.40
Spacing of 100mm	.73	.73
Spacing of 160mm	.83	.83

Each anchor is considered to be influenced by one edge and two other anchors (anchors on the diagonal are ignored), N_{rec} is therefore modified by 3 reduction factors:

$N_{rec'}$ = 22.0 x .75 x .73 x .83 = 10.0kN

$V_{rec'}$ = 22.8 x .40 x .73 x .83 = 5.5kN

$N_{sd} < N_{rec'}$ ∴ ✓
$V_{sd} < V_{rec'}$ ∴ ✓

Combined load check. This manufacturer uses the following formula to ensure the combined load does not exceed the anchor capacity at an angle:

$$\frac{N_{sd}}{N_{rec'}} + \frac{V_{sd}}{V_{rec'}} \leq 1.4$$

$$\frac{4.7}{10.0} + \frac{4.5}{5.5} = 1.28 < 1.4 \checkmark$$

Therefore the proposed bolt may be specified. Stainless Steel Grade A4 is appropriate for the exposure conditions. A version with fixture thickness suitable for the bracket thickness is chosen and the concrete thickness checked against the required structural thickness for this bolt.

CHANGING SPECIFICATIONS.

It is customary for specifiers to allow installers to use an alternative manufacturer's product. A full check of all performance and other parameters should be carried out before an alternative source is approved.

9 SITE TESTING[9]

Most members of the Association will offer a free on-site testing service to help determine anchor suitability in materials of unknown strength. They may make a charge for testing to check the quality of installation.

References

[1] CFA Guidance note: Light Duty Fixings
[2] Construction Fixings Association - An Introduction
[3] Guideline for European Technical Approval of Metal Anchors for use in Concrete. European Organisation for Technical Approvals (EOTA).
[4] CFA Guidance note: Anchor Installation
[5] CFA Guidance note: Fixings for Brickwork
[6] CFA Guidance note: Introduction to Bonded Anchors
[7] CFA Guidance note: Fixings for Blockwork
[8] CFA Guidance note: Fixings and Corrosion.
[9] CFA Guidance note: Procedure for Site Testing Construction Fixings
[10] CFA Guidance note: Introduction to European Technical Approvals (for "ETAG Metal Anchors for use in Concrete").

This Guidance note is published by the Construction Fixings Association
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