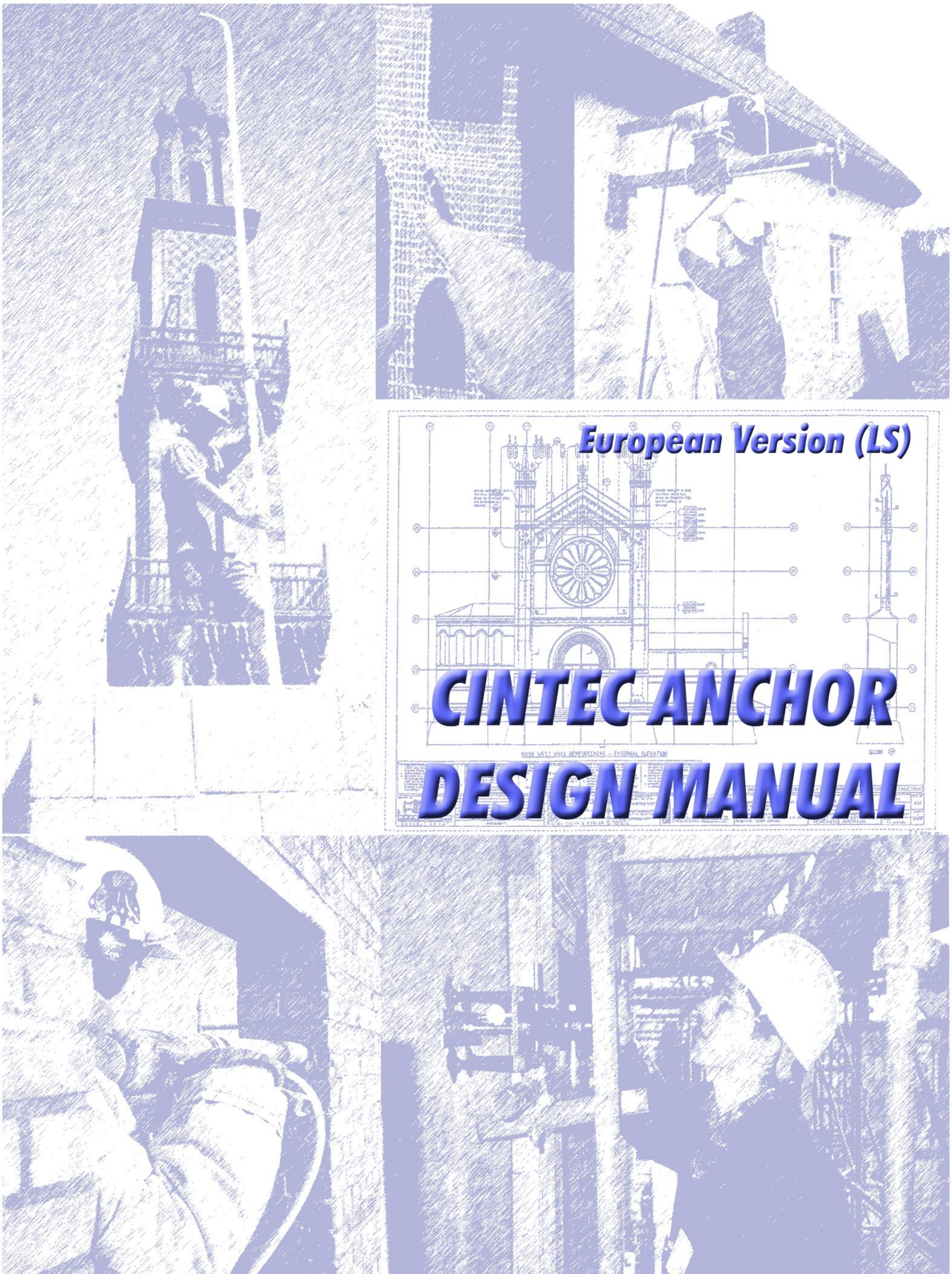

Edition 2 – June 2015

Introduction.

This manual has been prepared to assist both new and experienced users in assessing the feasibility of using the Cintec Anchor System for the repair, stabilization and strengthening of masonry and concrete structures. It has generally been written in the first person, to stress the cooperative team approach Cintec to provide an effective solution to the myriad of problems associated with distressed structures.

The words: client, installer, specifier, contractor, designer architect, conservator and engineer and any variations of these can be substituted where appropriate.

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Introduction to Masonry Strengthening and Reinforcement

1.1. **General**. When we speak of the repair, stabilization and strengthening of masonry or concrete structures, there is an assumption that the masonry (or concrete) exists and that it is deficient in some way. This deficiency can take two forms. In the first case, the masonry or concrete may have deteriorated to the point where it can no longer perform the functions for which it was intended or safety is compromised. In the second case, it may need to be reinforced to take new loads. Prior to the relatively recent development of the retrofitted strengthening methods, the standard practice was to dismantle and rebuild deficient masonry. This is a very disruptive and costly process, hence the impetus to find alternative methods.

1.2. **Definitions**. A *Skin or Leaf* is a wall with a thickness of half a brick. Masonry can be built in a number of configurations, including:

- Solid (single skin)
- Composite (multiple skins bonded together structurally)
- Cavity (multi skins tied together)
- Rubble (two skins with rubble fill)

1.3. **Components**. The main components of masonry are the individual masonry units, mortar and reinforcement. Some of the more common masonry units are brick, terra cotta, CMU, adobe, stone, or precast concrete. These units are usually bedded in and separated from each other by a mortar joint. In some cases the masonry is laid up without mortar, such as dry stone walls. Reinforcement can take the form of reinforced concrete elements built into the wall, embedded metal members, external reinforcement applied to the face of the wall, or external structural elements.

1.4. **Methods of Strengthening**. The structural strengthening methods covered in the other chapters of this manual can generally be applied to masonry. These include section enlargement, externally bonded systems, post-tensioning, and virtual strengthening. Generally speaking, masonry is not strong in tension, shear or bending - its main value as a structural material lies in its ability to withstand compression. However, all these characteristics can be improved through strengthening.

1.5. **Mortar**. The weakest component of a masonry system is typically the mortar - this is intentional. Mortar is intended to be the component that "wears out". The mortar is there to allow moisture to exit the wall through evaporation. In so doing, the mortar (particularly in temperate climates) is exposed to many more cycles of freeze-thaw than the masonry units. If the mortar fails to allow the moisture evaporate out of the wall, then the moisture is forced out through the masonry units themselves. This leads to freeze-thaw damage at both the interior (cavity) face and the exterior face and the surface of the unit eventually falls away. This type of damage can only be effectively remedied by complete replacement of the unit and it is much easier to repair the deteriorated mortar on a regular basis than it is to replace the actual masonry units. The mortar, when well designed, should act as a series of springs in the plane of the masonry wall and because it is more ductile and weaker than the masonry will absorb uneven stress distributions. These uneven stress distributions may be due to impact, settlement, thermal movements and overload.

1.6. **Repointing Failure**. The most common cause of masonry failure is the replacement of weak mortar with a much stronger mortar in a well intentioned but misguided attempt to "strengthen" the masonry elements. This is common where soft, permeable lime-based heritage mortar is repointed with a very strong and dense Portland cement mortar. The new, impermeable mortar acts as a dam and prevents the moisture in the wall from evaporating from the surface of the wall. Salts found in Portland cement are often deposited on the face of the masonry in the process. This is the unsightly efflorescence we see on the surface of the masonry units and leads to additional costs for surface cleaning. The accumulation of salts also clogs the pore structure of the masonry units and accelerates the deterioration process when exposed to freeze-thaw conditions. In addition, the insertion of a very hard, inflexible element at the front edge of the masonry units causes the face of the masonry to be subjected to a very high local compressive and shearing stresses. This combination of freeze-thaw damage and knife-edge stress loading can cause localized cracking leading to very rapid failure of the face of the masonry units.

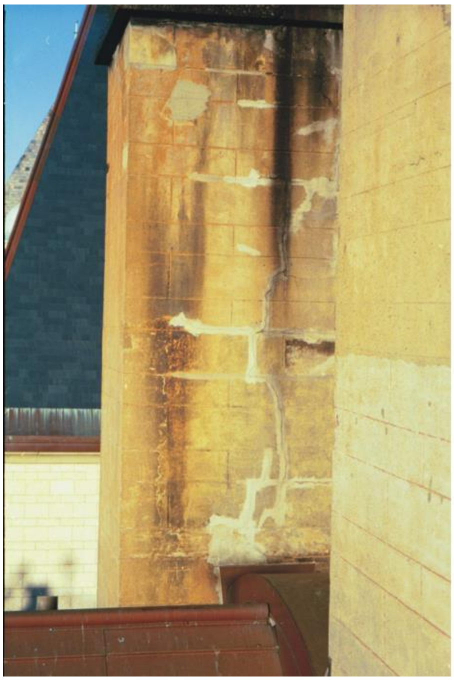


Figure 1.1. Masonry failure due to repointing with hard mortar.

1.7. **Evaporation Failure**. If the evaporation takes place from the inner surface of the exterior masonry units, (i.e. that surface next to the cavity) then the debris falling from the units accumulates in the cavity at a lower level. This eventually leads to a wedging action caused by

the accumulation of the debris in a confined space. This is the most common cause of bulging at lines of horizontal support.

1.8. **Oxide or rust expansion**. Corrosion of ferrous metals embedded in the masonry also contributes to masonry failure. Iron and steel frames are employed for fireproofing and aesthetic reasons (particularly prevalent in structures from the 1920's and 1930's). Unprotected steel angles are also used as shelf angles at regular interval in structures to support masonry veneers. Galvanized steel is also used as brick ties for anchoring or stabilizing individual skins of brickwork. As the masonry deteriorates water eventually comes into contact with the ferrous material. This moisture promotes corrosion of the iron leading to rusting where the products of corrosion can be 3 to 4 times the volume of the parent material, creating very high lateral and bursting forces. These forces open up cracks and joints in the masonry, leading to more water ingress and a vicious cycle of ever accelerating deterioration.

* * * * *

2. **Methods and Materials**

2.1 **Traditional Methods**. Traditional methods of strengthening masonry include:

- Replacement of mortar (repointing)
- Replacement or repair of individual units
- Rebuilding of sections of a wall

Whilst these methods may appear to be repair methods rather than strengthening methods, a weak structure will benefit from their employment.

2.2 **Section Enlargement**. While section enlargement is feasible, it is not often used in historic or landmark structures. As masonry structures are usually quite bulky by their nature the addition of extra volume can create appearance, space and clearance problems. However, sprayed concrete is one method of section enlargement that can be used where the above limitations do not apply but is not necessarily long lasting.

2.3 **Internal Strengthening**. Internal strengthening can be perpendicular to or in the plane of the face of the masonry. Perpendicular strengthening involves tying together the deteriorated masonry or tying the skins of composite or cavity systems. This type of strengthening can be achieved with Cintec socked and grouted anchors installed in holes drilled perpendicular or parallel to the wall face. Fire resistance and freeze-thaw resistance criteria are properties to be considered in the selecting this method of reinforcement.

2.4 **In-Plane Reinforcement**. In-plane reinforcement can be installed in any direction within the plane of the wall. Most applications involve drilling of holes and insertion of a Cintec anchor which is grouted. In some cases the existing void or core that forms part of the masonry unit, such as occurs in CMU and terracotta, can be used to accept a portion of the anchor. The air space in a cavity wall system may also be used to accommodate in-plane reinforcement. However, this is not usually an ideal practice as the introduction of reinforcement in the cavity may defeat the original design requirement for the cavity as an integral part of the building envelope. Care must be taken in this type of application, particularly in seismic zones, to ensure that the overall mass of the masonry is not overly increased and the load paths are changed. In-plane reinforcement can increase in-plane compressive, shear and tensile strength as well as out-of-plane shear and bending strength and can also be post-tensioned. Post-tensioning is advantageous as a strengthening method as it induces compressive stresses in the masonry whilst reducing the occurrence of tensile cracks in the system. The Cintec system lends itself to post-tensioning. As with other systems, fire resistance and resistance to freeze-thaw damage should be considered in selecting an internal reinforcement system making the Cintec anchor the ideal solution.

2.5 **Virtual Strengthening**. Many masonry structures were designed under empirical design rules, or even by traditional rules of thumb. There is much scope for the use of virtual strengthening in assessing such structures. Recent developments in codes for existing structures are now allowing greater latitude in allowable stresses for structures that have stood the test of time. Most masonry structures also benefit from the simple fact that the condition of mortar, being the weakest and most easily repairable element in the masonry system, is a good indicator of the structural integrity of the entire system. Advanced non-destructive testing (NDT) methods such as flat jacks and shove tests are a great help in assessing this condition. Details and discussions on these tests and many others can be found in reference websites and

texts on non-destructive testing. Finally, full scale load testing can also be used to confirm the actual capacity of masonry systems.

2.6 **Durability**. Some elements of the masonry system are intended to be capable of repair; in other words they will "wear out". The repair of these elements is expected to be an on-going preventative maintenance task. Ferrous metals must be protected from corrosion and synthetic materials must be protected from ultraviolet rays. The durability of any repair or strengthening will be very dependent on the successful elimination of the root cause of the deterioration or deficiency. We must treat the cause not the symptom. A good case in point is oxide jacking of encased steel members. Elimination of water ingress through effective repairs to joints and waterproofing helps this situation. However, there is still potential for the corrosion to continue, causing reoccurrence of the problem. Developments in cathodic protection provide a means to mitigate this problem.

2.7 **Fire Considerations**. Internal reinforcement systems are normally provided with fire resistance by the original masonry system. Where there is exposed steel, composites or adhesives, fire resistance is provided by encapsulation with a fireproof material. The Cintec cement based grouting system is inherently fire resistant.

2.8 **Field Applications**. The masonry strengthening methods discussed here have been used for some time in Europe. The more innovative and cost effective strengthening methods are gradually replacing the traditional demolish and replace approach to masonry repair and strengthening.

2.9 **Benefits and Limitations**. The main benefits of strengthening versus the traditional demolish and replace approach are:

Benefits	**Limitations**
• Time saving	• The cost of masonry repairs and strengthening can be expensive and approach the ARV. The cost effectiveness of the Cintec system often reduces the current Asset Replacement Value (ARV).
• Cost effectiveness	• The biggest cost element in strengthening is usually the access (scaffold) regardless of the method of strengthening selected. However the Cintec system may be installed by rope access where appropriate thereby reducing these costs.
• Reduction in disruption to the facility	• Surface fixed or chased / recessed methods will substantially deface the structure where there are surface decorations or mouldings. However the Cintec anchor system is a highly suitable method to strengthen masonry as it affords an unblemished appearance to surfaces which are decorative, rough cut stone or it is protected by heritage designation.

3 Cintec Anchor System

3.1 **Anchor Components.** The Cintec Anchor consists of four main components - the anchor body, the sock, the grout injection tube and the grout. Typically, holes are drilled into the masonry (or concrete) structure using diamond tipped coring drills to facilitate the anchor placement. The action of the diamond core drill is non-percussive and therefore has significantly less impact of the integrity of the structure particularly where fragile masonry exists . The engineer determines the locations of the holes.

3.2 **Anchor Function**. Each anchor body is surrounded by a grout annulus. The external diameter of the annulus is calculated to ensure that the relatively high tensile and shear loads in the anchor body are distributed over as large a surface area as necessary so that they remain compatible with the relatively weak capacities of the substrate.

3.3 **Anchor Body.** The anchor body is designed to safely transfer the load from one part of the masonry structure to another. Normally made from stainless steel sections to resist the effects of water corrosion inherent in many structures, the anchor body can also be made from a variety of materials depending on the function and the load to be carried.

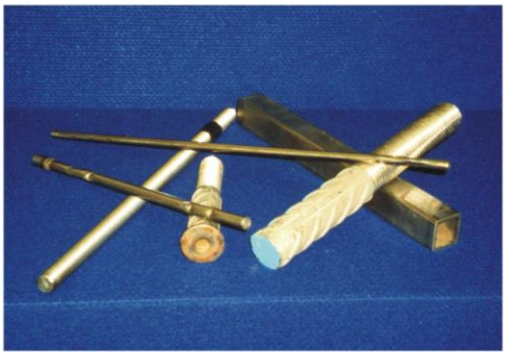


Figure 3.1. **Types of anchor body material.**

3.4 **The Sock**. The sock is made from a specially woven polyester fabric that can expand radially to fill the anchor hole and yet is unable to expand linearly. The purpose of the sock is to keep the grout in contact with the anchor body during the curing process and not permit it to flow to other parts of the structure where it may cause undesirable damage. Since the anchor length and hole diameter are known beforehand, it is easily to calculate the exact amount of grout required for each anchor, minimizing waste and ensuring rapid anchor inflation. The sock also permits excess grout ‘milk’ to seep through to the substrate forming a chemical bond with the substrate and optimizing the water-cement ratio in the grout annulus.

Figure 3.2. Various sizes of Cintec anchor sock.

3.5 **Grout Injection Tube**. The grout injection tube is a small diameter plastic tube that enables the grout to be pumped from the mixing pot into the anchor. Usually, the tube runs to the 'blind end' of the anchor ensuring that as the grout is pumped into the anchor, it fills the anchor uniformly from the back to the front, flushing all the air voids to the surface. For longer anchors two or more grout delivery tubes may be required. Tests have shown that the embedded plastic tube has little or no effect on the final strength of the grout annulus. For anchors with anchor bodies formed of hollow sections, the anchor body acts as its own delivery tube.

Figure 3.3. A typical heavy duty Cintec 'Multibar®' anchor showing the grout delivery tube and partially removed sock.

The Grout. Cintec's Presstec Grout is manufactured to very high specifications to ensure that it does not shrink on curing. Like many cementitious products, it will achieve 95% of its final strength in 7 days and full strength in 28 days. A rapid set version is also available. The grout has been age tested for 40 years and provides high levels of fire resistance.

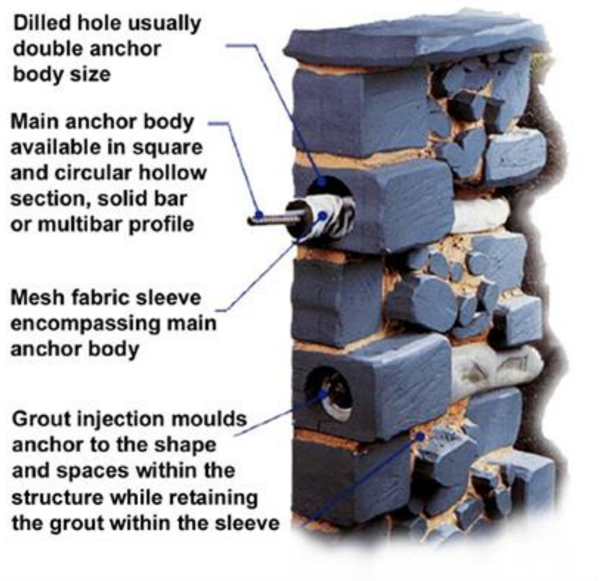
GÜTEÜBERWACHUNG MÖRTEL
DIN 18555
ÜBERWACHT

Figure 3.4. Preparing the grout in preparation for anchor inflation. Presstec grout is manufactured to DIN 18555 standards.

* * * * *

ANCHOR MATERIAL PRINCIPLES

The Principle of the CINTEC anchor system is illustrated below. The stainless steel anchor section has been inserted into in-situ materials in the diamond core drilled holes. The grout has been injected under pressure, inflating the sock throughout, but noticeably in the voids it is retained by the sock and ensures full inflation of the anchor.
Grout milk has passed through the expanded sock mesh to provide a chemical and mechanical bond to the in-situ materials.



Design Parameters

The Grout

Presstec is a one component mix of Portland cement, graded aggregate and additives which when mixed with water produces a pumpable grout which exhibits good strength development and minimal shrinkage.

Mixing

25kg of Presstec requires a maximum of 6 litres of water. Mixing can be carried out either in a bucket using a conventional hand held plaster mixer for small quantities or in a drum mixer for larger quantities. The mix time should be sufficient to break down any lumps and give a free flowing grout. Presstec should be added to water on mixing.

Pot Life

45-60 minutes dependent on ambient temperature.

Physical Performance

All tests carried out at 20 deg. C, 65% RH
Initial set - 160 mins.
Final set - 180 mins.
The grout is specially made to CINTEC's requirements. It has flow and anti-shrink additives which meet the requirements of the German DIN Standards. The grout also has been successfully tested using accelerated shrinkage tests. The grout bonds to the parent material through the sock as it is inflated. The strength of the in-situ construction to resist the anchor loads depends on the anchor body section utilized. If solid bar is used, the anchor body is deformed. If the anchor is circular the section is crimped. For square section material a plate slightly smaller than the bore hole is welded to the anchor at both ends to ensure that the grout strength is mobilized.

Typical Presstec Grout Strength with time for CINTEC Anchors

Time after injection	Compression	Tension
5 hours	1.4 MPa	0.4 MPa
1 day	23.0 MPa	2.9 MPa
28 days	40.0 MPa	3.3 MPa

Modulus at Elasticity, E= 28 kN/sq. mm @ 28 days

The following commented extract is about the two main kinds of PRESSTEC, "Standard" and "2000" based on the lab-report list of the producer with test results between 29.01.2012 and 05.07.2013.

Last supply, tested 05.07.2013:

Kind	Time	Standard	2000
Compressive Strength (N/mm²)			
	1d	30,13	36,80
	7d	45,78	55,37
	28d	54,00	64,70
Bending tensile (N/mm²)			
	1d	4,72	4,03
	7d	8,72	7,49
	28d	9,58	8,26
Water need (Litres/Kg dry mass)		0,215	0,215
Weight of Fresh grout (g/cm³)		2,0	2,04
Swell of volume in 24 hours (%)		4,1	2,8

Supplies tested between 29.01.12 – 10.05.13

Compressive Strength (N/mm²)				
	Average	28d	58,34	61,83
	Lowest	28d	52,80	53,08
	Highest	28d	73,95	70,13

The Steel

The steel section capacity can be determined by standard engineering calculations based on the steel strength. Typical values given below relate to North American Standards.

Characteristic Tension/Compression Strength of Standard Anchors Based on Steel Capacity

Installed anchor strength is dependent on the strength of parent material and the embedment length.

Anchor Type	Minimum Embedment	Minimum Value
8mm dia. x 1 mm wall	50 mm.	4.0 kN.
10mm dia. x 1 mm wall	50 mm.	6.0 kN.
15 x 15 mm x 1.5 mm wall SHS	100 mm.	17.0 kN.
20 x 20mm x 2mm wall SHS	100 mm.	30.0 kN.
30 x 30 mm. x 3 mm, wall WSA	100 mm.	66.0 kN.

Characteristic Shear Strength of Standard Anchors Based on Steel Capacity

Installed anchor strength is dependent on the strength of parent material and the embedment length.

Anchor Type	Minimum Value
8 mm. dia. x 1 mm. wall	2.4 kN.
10 mm. dia. x 1 mm. wall	3.0 kN.
15 x 15 mm. x 1.5 mm. wall SHS	4.8 kN.
20 x 20 mm. x 2 mm. wall SHS	10.0 kN.
30 x 30 mm. x 3 mm. wall WSA	22.5 kN.

Characteristic Moment Capacity of Standard Anchors Based on Steel Capacity

Installed anchor strength is dependent on the strength of parent material and the embedment length.

Anchor Type	Minimum Value
8 mm. dia. x 1 mm. wall	9 N-M.
10 mm dia x 1 mm. wall	14N-M.
15 x 15 mm. x 1.5 mm. wall SHS	74 N-M.
20 x 20mm. x 2mm. wall SHS	175 N-M.
30 x 30 mm. x 3 mm. wall WSA	590 N-M.

Structural Stainless Steels

Type	Grade	Proof Stress	Tensile Strength	Elongation
Austinitic Stainless Steel	304S11	180 MPa.	480 MPa.	40%
	304S15	195 MPa.	500 MPa.	40%
	304S16	195 MPa.	500 MPa.	40%
	316S11	190 MPa.	490 MPa.	40%
	316S13	190 MPa.	490 MPa.	40%
	316S31	210 MPa.	510 MPa.	40%
	316S33	210 MPa.	510 MPa.	40%

4 Engineering Principles

4.1 This manual adopts the principle of Limit State Design (LSD) or the Load Factored Resistance Method (LFRD). Design procedures are based on the publications of the British Standards (BSI) and related Eurocodes as well as masonry industry sources. A critical step in the process is the assessment of the strength of the parent material (substrate). As this can often only be undertaken by visual inspection of the materials, the designer must make an educated estimate of the strengths of the material in-situ. Sources for data can be derived from historic engineering and builders' textbooks and suppliers' catalogues.

4.2 **Design Procedure and Standard Checks**. The design procedure for Cintec Grout Anchors for use in stone, brick and terra cotta masonry is shown in the tables below. Providing the grout installation has been performed in accordance with Cintec requirements, the grout element will not fail in crushing shear or tension. As the anchor system tends to fail in the substrate, leaving the anchor body intact the design procedure should concentrate primarily on determining the properties of the substrate. For alternate substrates, for example concrete, advice should be sort from Cintec International Ltd.

4.3 **Typical Masonry Properties**. A critical step in the design process is the assessment of the strength of the parent material (substrate). As this can often only be done by visual inspection of the materials, the design engineer must make an educated estimate of the strengths of the material in-situ. Typical masonry properties are shown in the table below. Where there is any doubt, the true value must be obtained by an on-site test.

Substrate	Compressive Strength	Allowable bearing	Allowable shear	Remarks
	Values in N/mm^2			
Brick masonry	13-20	2	0.2	
Stone	35-70	7	0.2	
Clay terra cotta tile	5-7	0.7	0.1	Very little test data available
CMU concrete block	8-14	3	0.2	
Concrete	21-48	7	0.4	

4.4 **Anchor Body Strength**. We check the strength of the steel anchor body to ensure that failure does not occur in the anchor body. The steel we use is usually stainless steel produced to BS 6744. The reason for using stainless steel is that it exhibits an enhanced performance which taken over the life of the structure can offer savings when costs and maintenance are taken into account. BS 6744 provides for two strength levels in the commonly used size ranges.

Plain bars: 250N/mm^2 characteristic strength, 8-16mm diameter (preferred bar sizes)
Ribbed bars: 460N/mm^2 characteristic strength, 8-40mm diameter (preferred bar sizes)

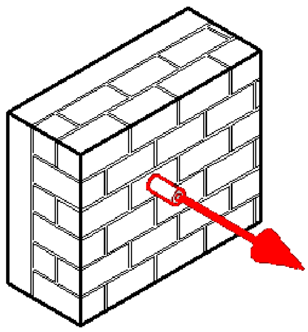
In other words, no design or detailing changes are necessarily required when replacing carbon steel with stainless steel. However, BS 6744 has been recently revised (BS6744:2001) and account has been taken of recent developments allowing for bar diameter, method of manufacture and chemical composition as indicated in Table 3.1[1].

Steel Designation		**Proof stress $R_{p0.2}$ or characteristic strength (N/mm^2)**			
BS EN 10088-1:1995	**Corresponding to:**	**Plain bar**	**Ribbed bar diameter (mm)**		
			3-5	**6-16**	**20-40**
1.4301	BS6744:1986 304S31	250	650	500	500
1.4436	BS6744:1986 316S33	250	650	500	500
1.4429	High proof	-	650	650	650
1.4462	Duplex	-	650	650	500
1.4529	Super austenitic	-	650	650	650

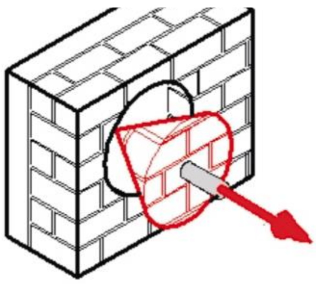
Table 3.1: Characteristic strengths of austenitic and duplex stainless steels.

Notes to Table 3.1:
1. Steel designation 1.4462 is a duplex stainless steel; the remainders are austenitic stainless steels.
2. Steel designations 1.4429, 1.4462 and 1.4529 (shaded) are not covered by BS 6744.
3. Steel designations 1.4301 and 1.4436 will be the most commonly specified for use as reinforcement; the remaining three steels (shaded) are for more specialized use.

4.5 **Bond Pull-Out Resistance**. We check the bond pull-out resistance to ensure that the bond between the grout-sock interface and the substrate does not fail in pull-out. The bond pull out strength is typically 0.2N/mm^2 measured at the circumference of the drilled hole. This figure is based on a 100 - 200% safety factor over actual full-scale load tests. We often reduce the bond pull-out strength to as low as 0.1N/mm^2 in very dense, smooth substrates like granite or where the substrate material is known to be weak or friable.



4.6 **Masonry Tensile Failure**. We undertake a failure cone pull-out resistance check to ensure that the parent material has sufficient capacity to resist the tensile loads generated in the anchor body. Pull-out and bearing strength of the substrate is based on the BSI standard procedure using an appropriate tensile stress. Pull-out strength in terra cotta units is based on a very conservative value and load tests have always proven that failure load is much higher than we calculate. To do this we assume that the failure surface is that generated by the frustum[2] of a 45º cone as shown in the



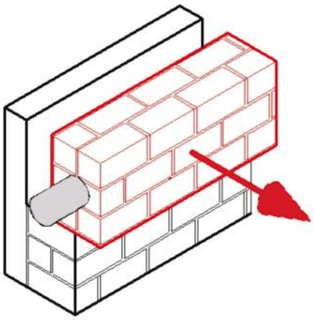
[1] Taken from Concrete Society Technical Report No. 51 dated 1998.
[2] The correct spelling is frustum not *frustrum*

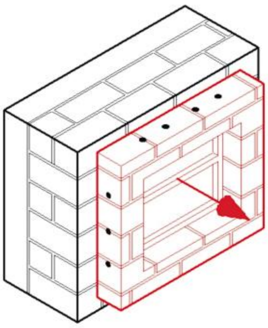
formula below. The value of the masonry tensile capacity is typically assumed to be $0.2N/mm^2$.

$$A_{net} = \pi\left(\frac{d}{2}+l\right)\sqrt{\left\{\left(l-\frac{d}{2}\right)^2+l^2\right\}}$$

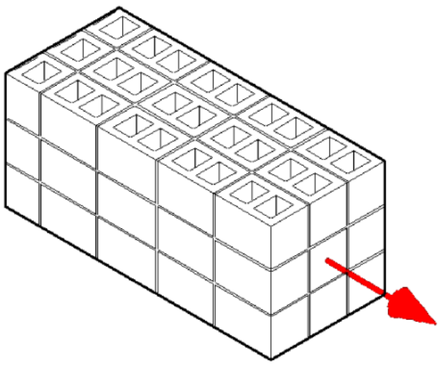
Where: A_{net} = area of frustum
d = anchor hole diameter
l = sock length

4.7 **Mortar Joint Check**. We check the mortar joints to ensure that the mortar has sufficient strength to transmit the loads from individual anchors into the global masonry substrate. The failure path can be complex and engineering judgment is required to identify which of the several potential options is the most likely. Further advice is available from Cintec International Ltd if required.





4.8 **Hollow Core Units**. In the case of hollow units (CMU or terracotta) the grout bulb will expand into the void between the webs of the hollow block to approximately twice the diameter of the anchor hole. This creates a 'stopper' at every web/anchor intersection and is particularly effective at resisting tensile loads. We check the load from the enlarged grout bulb bearing against web acting in shear. The key to this very effective form of anchorage is to calculate the resistance required based on the total number webs resisting the load. Shear or bearing loads are resisted by the total cross section area of web in accordance with the following formula:



$$V_c = n\pi t d \sigma_v$$

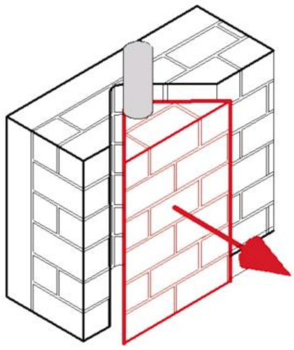
Where: V_c = total shear resistance
n = number of webs
t = web thickness measured parallel to anchor
d = anchor hole diameter

4.9 **Bearing Resistance of the Substrate.** We undertake a bearing resistance check of the substrate to ensure that the parent material does not fail in crushing in the vicinity of the anchor. The safe bearing strength for shear loads and/or bending stresses from eccentric loads on sound brick masonry is 2N/mm^2. We calculate the bearing area on one-half the circumference of the hole, not the projection of the hole's diameter as shown in the formula below. The sum of the interaction formula for combined stresses should not exceed 1.0.

$$V_b = \frac{\pi d l \sigma_b}{2}$$

Where: V_b = total bearing resistance
d = anchor hole diameter
l = sock length
σ_v = masonry bearing stress

4.10 **Masonry Shear Resistance**. This is a primary mode of failure and can occur in both the horizontal and vertical planes. We check the shear resistance toward the free edge of the parent material to ensure that the parent material does not fail in shear due to anchor loads near and perpendicular to a free edge. We assume that the forces are distributed through the masonry at 45º as shown in the illustration opposite and in the formula below. If the shear load in the anchor body exceeds the tensile capacity of the substrate then placing the anchors deeper (further away) from the rear face of the masonry can help alleviate the problem.



$$V_s = 0.56 d l \sqrt{\sigma_c}$$

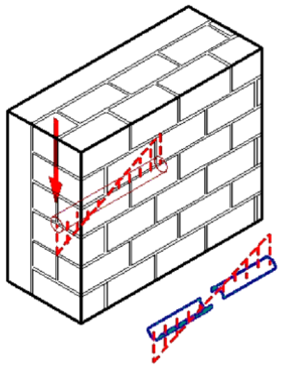
Where: Vs = total tensile resistance
d = anchor hole diameter
l = length of sock
σ_c = masonry characteristic strength

4.11 **Design for Moment.** The design of Cintec SHS anchors to resist moments principally relies on the bearing capacity of the masonry where the stress is concentrated at either end of the embedded anchor. The moment capacity of the steel section also needs to be checked in accordance with normal structural principles, but this will rarely be the governing factor and the grout outside and inside (if applicable) the anchor will enhance the calculated capacity giving a larger factor of safety. There are two stages to the process:

4.11.1 **Stage 1 - Evaluate Bearing Failure Moment**. This is a potential failure mode for weak or friable substrates in both the horizontal and vertical planes, where the shear load in the anchor body is too great for the bearing capacity of the masonry and the substrate fails in crushing. To calculate the bearing capacity of the masonry we assume that the perpendicular force at the end of the anchor generates a moment within the anchor body accompanied by a linear stress distribution about the mid point of the anchor. This is illustrated below and in the formula below. Using bending theory we can then determine the bearing stress by dividing the internal anchor moment by the section modulus generated by the bearing area.

$$M_b = \frac{\sigma_b l^2 d}{3}$$

Where: M_b = anchor resisting moment
d = anchor hole diameter
σ_b = masonry compressive stress (concentrated load)
l = anchor embedment length



4.11.2 **Stage 2 - Evaluate the Moment Generated**. The moment generated is due to the perpendicular force on the anchor and the eccentricity of loading from the masonry face as shown in the formula below:

$$M_b = F\left(e + \frac{l}{2}\right)$$

Where: F = perpendicular force
E = eccentricity

4.12 **Design Information**. The following information shown in Table 4.2 must be obtained in order to complete the anchor design process.

Design Information		
Factor	**Symbol**	**Remarks**
Hole diameter	d	Assume d_{min} = 2λ + 8mm where λ is the maximum anchor body cross section dimension
Hole length	l	Socked length of anchor
Thread factor	t_f	For SRT[3] only; usually 0.75
Characteristic masonry strength	$f_c^{'}$	
Factored tensile load on anchor	T	If applicable
Factored shear load on anchor	W	If applicable

Table 4.2 - Design Information

[3] SRT – solid threaded bar

4.13 **Design Calculations**. The following factors shown in Table 4.3 must be calculated in order to check the anchor design.

Design Calculations		
Factor	**Symbol**	**Remarks**
Bond area	A_{cyl}	$A_{cyl} = \pi dl$
Bond pull-out resistance	P_r	$P_r = A_{cyl}\left(\frac{\sqrt{f_c'}}{10}\right)$
Anchor body tensile capacity	T_b	For threaded bar: $T_b = t_f \frac{\pi b^2}{4} f_y$ Where *b* is the nominal bar diameter and f_y the 0.2% steel stress.
Anchor body shear capacity[4]	S_b	For threaded bar: $S_b = t_f \frac{\pi b^2}{8} f_y$ Where *b* is the nominal bar diameter and f_y the 0.2% steel stress.
Bearing Area	A_b	$A_b = \frac{\pi}{2} dl$
Shear resistance at free edge	P_{ve}	Where the anchor is within 3 hole diameters of the free surface $P_{ve} = 0.34dl\sqrt{\sigma_c}$
Bearing moment	M_b	$M_b = F\left(e + \frac{l}{2}\right)$ Where *F* is the perpendicular force on the anchor and *e* the eccentricity of loading

Table 4.3 – Design Calculations

[4] Using Mohr's circle, the maximum shear capacity is 50% of the maximum tensile capacity

4.14 **Design Checks**. The following checks shown in Table 4.4 must be undertaken in order to prove the anchor design.

Design Checks	
Check	**Calculation**
Combined load check	Ensure that the sum of the ratios for applied shear and allowable shear; applied tension and allowable tension do not exceed unity.
Masonry shear check	Ensure that the masonry shear resistance is adequate (paragraph 4.9).
Masonry tensile check	Ensure that the bond pull-out resistance (paragraph 4.4) and the masonry tensile capacity (paragraph 4.5) are adequate.
Masonry joint check	Conduct a study to determine whether the masonry panel will fail in a global manner once the anchors are inserted (paragraph 4.6).
Edge shear check	If the anchors are placed within 3 hole diameters of an edge, or where the assumed 45º failure cone intersects a free edge, recalculate the strength of the anchorage using a reduced (60%) masonry capacity.
Bearing stress check	Ensure that the local bearing stress due to eccentric loading does not exceed the masonry characteristic strength (paragraph 4.10) particularly in weak and friable substrates.

Table 4.4 – Design Checks

4.15 **Groups of Anchors**. Multiple anchors (a group) may be required to attach structural members such as shelf angles, beam brackets and pipe supports. Anchor spacing within in a group is dependent on the ability of the substrate to transfer the loads within the anchor group. For attaching structural members, anchor holes are typically twice the diameter of the anchor body plus the diameter of the grout delivery tube (typically 8mm) and as an initial design assumption we use an minimum anchor spacing of twice the drilled hole diameter measured from center to center of the holes. At the detailed design stage, this distance should be checked to ensure that it conforms to the minimum edge distance calculation if practicable.

4.16 **Post-Tensioned Anchors**. Cintec anchors can be post-tensioned by tightening the attachment nut to a specified torque. Such anchors will normally have two grout delivery tubes; one to deliver grout to the far end of the anchor to provide a key to resist the torque load and a second to grout up the anchor once the torque load has been applied.

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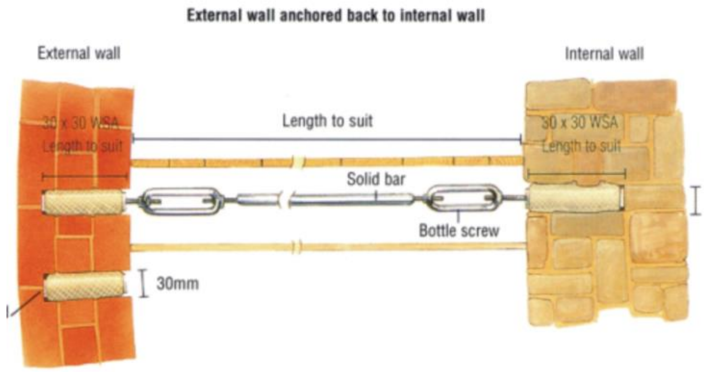
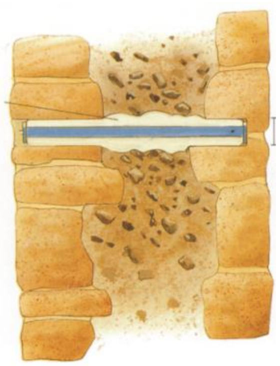
5 Common Solutions

5.1 **Bulging and Fractures**. Bulging frequently occurs due to the lack of bond between brick skins or straight joints at wall junctions when the loadings are altered. Fracturing is often caused by local subsidence or the failure of timber lintels and bond timbers or alterations and additions to the original structure. Stitching the masonry prevents further movement taking place that would threaten the stability of the structure.

5.1.1 **Solution**. To control bulging and fracturing, Cintec anchors can be employed in two distinct ways; either by replacing the bond between the brick skins or by tying the structure back to another structural element. In the latter case the second structural element could be an internal transverse wall, RC floor slab, wooden floor joist, or convenient structural steel member.

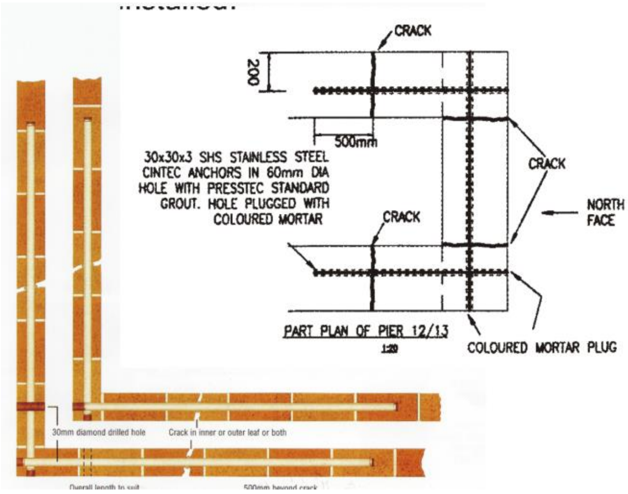


5.1.2 **Design Theory**. Calculate the wind loading on the wall section (pressure or suction) using appropriate standards and apply this load to a unit area of masonry surface. Assume a nominal anchor distribution (typically 900mm x 450mm centers, horizontally and vertically) and calculate the area of wall that each anchor supports. Assume that force in each anchor is equal to the loading on the wall. Design the anchor body to resist this load and calculate the sock diameter within each layer of wall to carry the load into the masonry. Compare the vertical load in the wall at the point the anchor is required allowing for partial safety factors in respect of dead and live loads as necessary. Apply 5% of the vertical load as a tying force to each anchor, calculating anchor body size and sock diameter as above, adopting the highest load (wind or vertical) for final design.



5.2 **Parapet Corner Cracking**. The freeze-thaw action experienced by parapet walls, particularly at the roof level of older masonry buildings, often leads to the build-up of internal stresses. The stresses are greatest at the corners or other similar changes of direction and lead to tensile cracks forming in the masonry. Similar cracks develop where masonry has been built without a proper bond between a façade wall and cross walls. Sand and other masonry debris falls into the crack, preventing the broken masonry from moving back together again. Water then enters the crack, expands on freezing forcing the crack wider allowing more debris to enter at the end of the freeze-thaw cycle. If left untreated the crack is 'jacked apart' in a progressive manner until the wall eventually fails. Similar failures also occur where the chimney breast meets the gable wall of domestic dwellings.

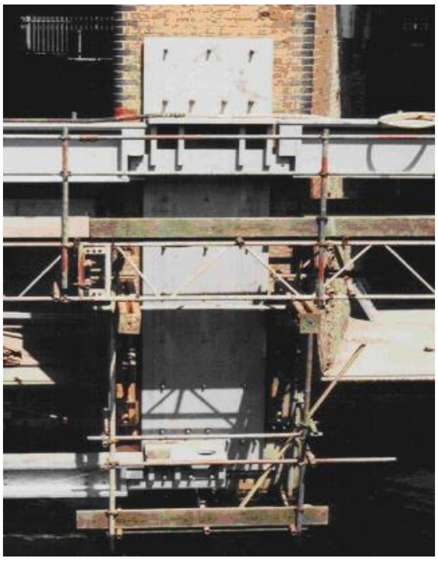
5.2.1 **Solution**. Cintec anchors can be installed orthogonally into both wythes of wall in order to prevent any further movement of the corner. Cintec anchors also offer the potential for post-tensioning thereby increasing the potential to close the cracks.



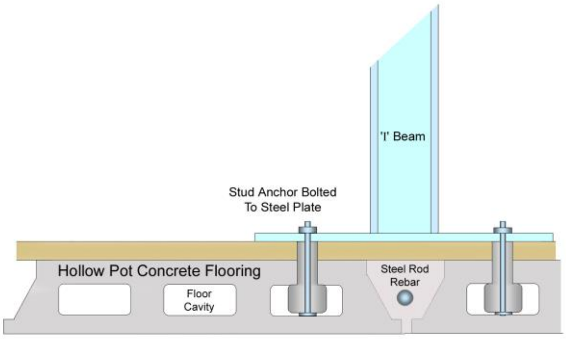
5.2.2 **Design Theory**. Calculate to force necessary to cause the wall to fail in tension at the corner joint by evaluating the area of the masonry in the vertical plane and multiplying by the appropriate tensile capacity for the brickwork (for example $0.1f_c^{1/2}$). Calculate the numbers of Cintec anchors required to resist this tensile load per unit area. In very weak substrates, consider increasing the anchor hole size to reduce the effective bond stress.

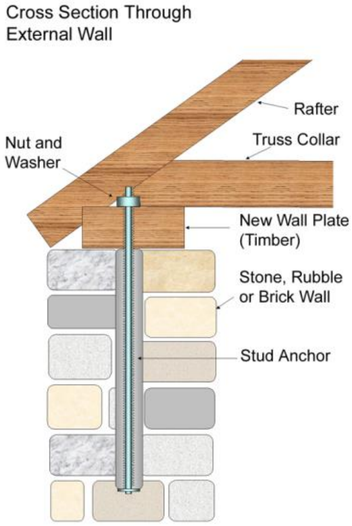
5.3 **Wall Plates, Brackets and Fixings**. Often the engineer is required to design a system to transfer an external load into a masonry wall. Subject to the wall being capable of withstanding the proposed loading, Cintec anchors are particularly suitable for attaching brackets, wall plates and related fixings whenever the parent substrate is weak or where the loadings are would create high local stresses.

5.3.1 **Solution**. Cintec anchors are usually installed in pairs to a depth where the imposed loads on the masonry are matched to the masonry strength. Anchors may be installed horizontally or vertically, into voids or solid material.



Design Theory. Assume that the top group of anchors acts in tension, whilst the remainder takes the shear load. Calculate the moment arm for the tension anchors assuming that the anchor plate remains stiff and rotates about the toe. Calculate dead and live loads in the usual way and determine embedment and bearing lengths as appropriate.





5.3.2 **Arch Stabilization**. May require use of the Cintec software for Finite Element Analysis Please contact Cintec International Ltd (+44 (0) 1633 246614

5.3.3 **Tower Strengthening**. May require use of the Cintec software for Finite Element Analysis. Please contact Cintec International Ltd (+44 (0) 1633 246614

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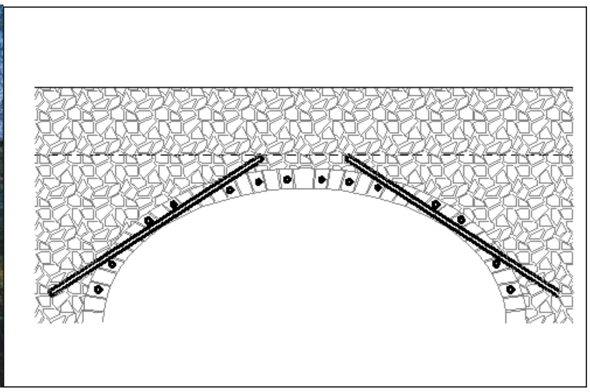
6 Special Applications

6.1. **Historic Masonry**. Appearance and compatibility are important considerations in selecting masonry strengthening methods for historic structures. External systems tend to disrupt the appearance of the structure, whilst internal systems are concealed. As much as possible, historical preservationists prefer using materials that are compatible with the original materials. They also prefer systems that are reversible. Natural, cement based products are historically compatible with older structures; polymers and resins are contemporary materials and whilst efficient, are not. Work on historic structures must conform to the standards of the ICOMOS Charter of Venice and many preservation offices around the world have adopted this or similar standards. The Cintec system is widely approved by many heritage and conservation authorities around the world and has been employed on many World Heritage sites. Additionally Cintec are an active participant of NIKER – The New Integrated Knowledge Based Approach to the Protection of Cultural Heritage from Earthquake Induced Risk.

6.2. **Civil Engineering Structures**. Cintec anchors have been used of many years for the repair and reinforcement of a number of civil engineering structures. The ARCHTEC system for reinforcement of masonry arch bridges has been proven by full-scale testing both in the field and the laboratory to increase the load-carrying capacity of masonry arch bridges. Cintec ground and rock anchors have been used to reinforce retaining walls, seawalls and railway embankments, and are particularly useful in the repair of hydraulic structures such as dams. The sock retains the grout, thus preventing pollution of the watercourse.



Design of repair and upgrading of civil structures is a complex process. The applications are many and varied. We recommend that the designer of such projects wishing to assess the feasibility of a given application contact us at an early stage in the project. We retain structural engineers experienced in retrofit and upgrading of civil structures to provide assistance to project engineers at all levels.

6.3. **Parapet Strengthening**. Over the years the high concentrations of road salts used for deicing operations on many of our older bridges has caused the bond between the masonry elements in the parapet wall to be severely weakened. In some cases the mortar is no longer present at all, particularly at the point where the road surface runs into the parapet. Masonry parapets are vulnerable to accidental damage from vehicle impact and there is a high risk of the parapet being displaced completely if the impact is great enough. If this occurs where the masonry bridge passes over another road or railway line, the results could be catastrophic. Cintec anchors are ideally suited for retrofitted strengthening of masonry bridge parapets combining ease of installation with strength and preservation of the historic architectural appearance. Typically the anchors are inserted longitudinally along the length of the parapet and vertically to secure the parapet to the spandrel walls. The spandrels are then connected together by inserting anchors transversely through the body of the bridge. For further details please contact Cintec International Ltd (+44 (0) 1633 246614.

6.4. **Seismic Upgrading**. Increasingly, masonry is being strengthened both internally and externally to resist seismic forces. In addition to increasing the shear, axial and bending strengths, retrofitted reinforcement also increases the ductility of the masonry, significantly improving the out-of-plane resistance to seismic loads. The perfect choice for this is Cintec being an active participant of NIKER – The New Integrated Knowledge Based Approach to the Protection of Cultural Heritage from Earthquake Induced Risk. Cintec seismic upgrade and retrofitted projects are to be found across several continents of the world.
Further details are available from Cintec International Ltd (+44 (0) 1633 246614.

6.5. **Blast Protection**. Many of the proposed strengthening methods can also contribute to the resistance of the structure to blast loads, either intentional or accidental. The loads on masonry structures due to blast loads have a similar effect to seismic loads and damage levels can be comparable. Internal skins made from either steel or cast in-situ reinforced concrete probably offer the best protection and have the added benefit of providing spall protection, however they are costly and reduce significantly the amount of available space inside the building and increase the vertical loads on the foundations. External reinforcement has the advantage easier application but has limited applicability where appearance is a consideration. Layers of geotextile or elastic membranes can also be applied to the interior surface of the wall, however care must be taken not to impair the movement of moisture through the wall and of course all internal finishes must be replaced. Alternatively the wall can be fitted internally with reinforcing bars passing through either the masonry units or the cavity between the inner and outer skins. Such an arrangement not only increases the ductility of load-bearing walls, but also improves the performance of masonry infill panels to out of plane loading. Further details are available from Cintec International Ltd (+44 (0) 1633 246614.

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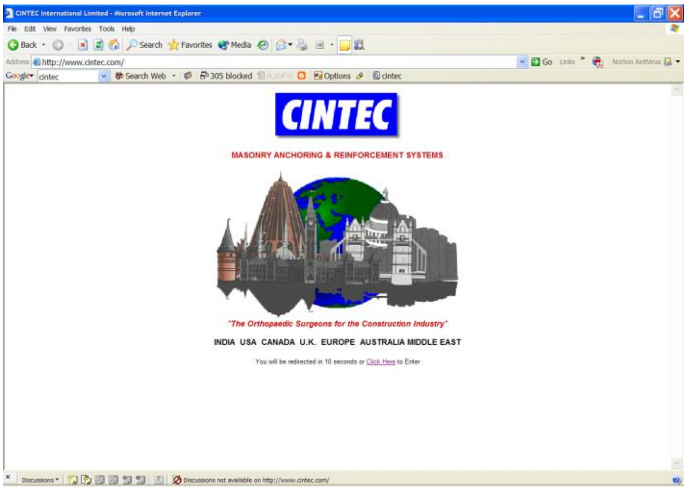
7 Cintec Reference Data

7.1 **Testing**. Cintec's approach to testing is to test at full scale, replicating as close as possible the intended application. Major tests have been witnessed and certified by Licensed Professional Engineers and/or Certified Testing Agencies. Some tests are undertaken under controlled laboratory conditions while others are field tests of actual applications. Examples include full-scale arch bridge tests to failure, tensile and shear tests, freeze-thaw durability and fire resistance testing in a variety of substrates. Hardcopy test data selected for relevance to a specific application is available on request or through the Cintec website:

7.2 **Cintec's Website** - www.cintec.com



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