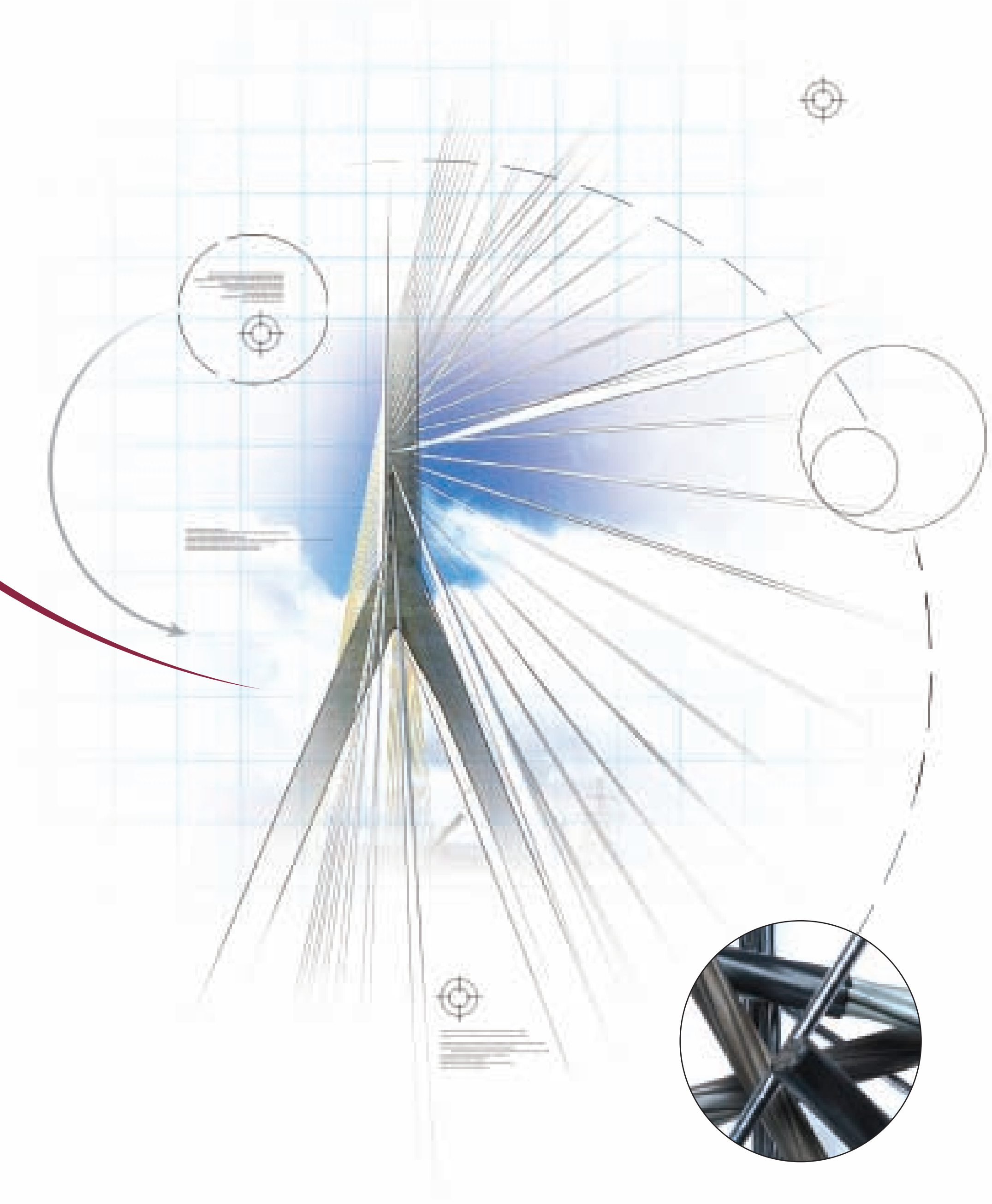
High quality prestressing wire & strand for construction product applications

Construction Products

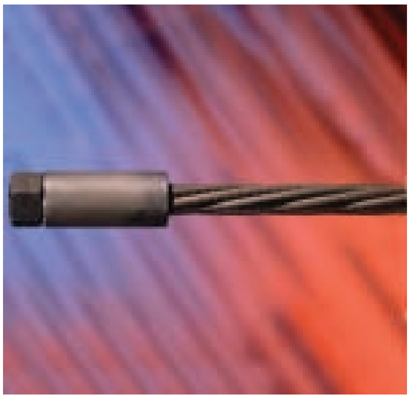


BRIDON

Green Bridge, Australia

Bridon - the world's leading specialist in the manufacture of wire and rope solutions for the most demanding applications, delivering reassurance through unrivalled experience.

Specialist prestressing wire & strand solutions for the construction industry



Drawing from a background of long standing experience and technology, Bridon is an acknowledged world leader in the design, manufacture, development and supply of prestressing wire & strand to meet the needs of the construction industry.

The *Difference* is BRIDON

Contents

ISO 9001

Bridon operates quality management systems which comply with the requirements of EN ISO 9001:2000. These systems are assessed and registered by accredited certification bodies.

ISO 14001

Bridon operates environmental management systems which, where required by legislation or risk, comply with the requirements of EN ISO 14001:2004 and are assessed and registered by accredited certification bodies.

Stay Cable Strand for Stay Cables

Today's stay cable structures require strand with increasingly advanced properties. Bridon's 7-wire Stay Cable Strand has been designed to meet the particular needs of these complex structures.

Recent years have seen the rapid development of stayed structures and in particular the stay cable bridge.

Modern stay cable techniques allow installation of complete stay cables and at the same time offer the ability to replace individual stays if necessary.

Fabrication and installation of stay cables using 7-wire strand have many similarities with post-tensioning. However, the demands exerted on the strand by a stay cable system are somewhat different and more onerous than is the case with traditional post-tensioning applications. In particular, the high stress variations imposed by bridge loadings on stay cables demand that the strand has a significantly improved fatigue performance in addition to the usual characteristics of prestressing stand. The strand must also have good resistance to multi-axial stresses and to stress corrosion.

In order to achieve these high performance requirements, Bridon has developed a 7-wire strand specifically for stay cables with properties which are significantly enhanced over those of conventional strand.

By the use of special steel grades and manufacturing processes Bridon is able to offer a product which meets the unique requirements of stay cable designs and the recommendations of the American Post Tensioning Institution and the FIB.

Stay Cable Strand can be supplied either ungalvanised or galvanised and in a fully blocked and sheathed condition tailored to the designer's particular requirements.

The strand complies fully with most well known National and International standards for bright and galvanised prestressing steels and also with the recommendations of the American Post Tensioning Institute and the FIB for stay cables.

Length Measurement

As the processes employed on the site erection of stay cables have become more refined and more demanding, so too has the need to supply Stay Cable Strand in accurately marked lengths.

Bridon has developed a length measurement system which measures and makes strand to an accuracy of +/- 0.01%. As well as minimising waste on site, this allows the stay cable installer to greatly reduce the time and costs involved in erecting each cable.

Chartist - Stay Cable Bridge, UK

Dee Estuary Flintshire - Stay Cable Bridge, UK

Corrosion Protection

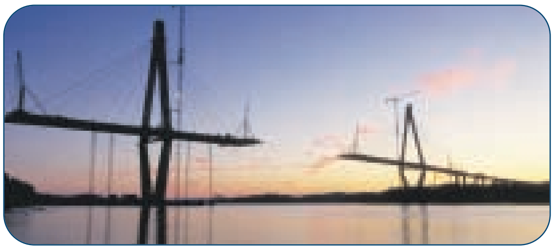
By their very nature stay cables are exposed to the severities of the elements and corrosion protection is therefore of fundamental importance in the design and performance of stay cable strand.

This can be achieved by two methods or a combination of the two:

Galvanised Strand

By using the hot dip galvanising process, stay cable strand can be supplied with minimum zinc weights ranging between 190g/m2 and 350g/m2. Zinc weights can be adjusted to suit customer's specific requirements whilst still maintaining the strand's characteristics and superior fatigue performance.

Where a wedge and barrel type gripping system is to be used then it is normal for a drawn galvanised strand to be supplied. By this process the wire is galvanised before the final wiredrawing operation resulting in a smooth finish on the strand which offers adequate corrosion protection with minimum interference to the gripping mechanism.



Uddevalla - Stay Cable Bridge, Sweden

Blocked and Sheathed Strand

In this case the strand is coated in a highly corrosion-resistant grease or wax conforming to the recommendations of both the American Post Tensioning Institute and the FIB, by the continuous hot extrusion method, in either high density polyethylene or polypropylene to a minimum radial thickness of between 1.00mm and 2.00mm, once again conforming to the recommendations of both the American Post Tensioning Institute and the FIB.

Special tests to confirm the integrity of the blocking medium and the impact resistance of the sheath are performed on equipment specifically developed by Bridon.

From the initial design consultation to the final product installation Bridon provides its customers with the complete bespoke service.

Bridon has a large and modern facility to produce galvanised bridge wire for suspension cables, either for aerial spinning or for parallel wire bundles made on site. Typically such wire is in sizes between 5mm and 7mm in diameter with tensile ranges of between 1570 and 1860 N/mm^2 and a minimum zinc coat weight of 300g/m^2. In addition, this demanding application requires a high level of ductility and is assured by appropriate adhesion and continuity test.

Dedicated development work alongside one of the world's leading steel making groups have resulted in a new range of 1860 N/mm^2 and 1960 N/mm^2 strength wires, which are now commercially available.

Bridon galvanised bridge wire can be supplied in coils of between 250kg and 2000kg which are suitable for the rapid pay-off systems employed in aerial spinning or for laying into parallel wire bundles.

Jiangyin Suspension Bridge, PR China

Jiangyin Suspension Bridge, PR China

Main Cable Wire for the Second Tacoma Suspension Bridge, USA

Prestressing Strand

Pioneered by Bridon in the UK, prestressing strand has been developed and adapted to meet the changes of an increasingly demanding market. The unique product range and very low relaxation properties of all BRIDON's prestressing strand makes it suitable for the complete scope of prestressing applications.

Product Range

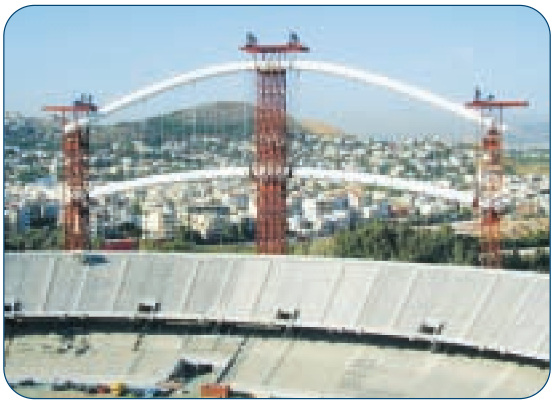
Bridon was the first manufacturer of prestressing strand in the UK, and is now the foremost producer both in product range and volume, in the country.

From the early years of prestressing the pattern of demand has been changing and Bridon has adapted and developed its product range to meet these changes: DYFORM® Strand, a compacted strand was a Bridon invention; the greasing and simultaneous extrusion of a plastic sheath over strand for use in unbonded tendons was pioneered by Bridon and now Bridon is leading the way in developing and supplying higher strength strand. All of Bridon's prestressing product range is produced with very low relaxation properties making it suitable for use in all prestressing and post-tensioning applications. The combination of Bridon's unique product range and proven product quality in performance in projects worldwide has made Bridon 7-Wire Prestressing Stand the recognised leader in its field.

Bridon 7-Wire Prestressing Strand is produced in three types: Standard, Super and DYFORM® in sizes ranging from 8.00mm to 18.50mm diameter. Bridon can meet the requirements of all the main international specifications for prestressing stands, the most common of which are BS 5896, ASTM A416 and Pr EN 10138.

(More detailed information is provided in the 'Technical Data' section of this brochure.)

Concrete Gravity Oil Storage Base for South Arne Platform, UK



Lifting of the structural steel elements in the Athens Olympic Stadium using 18mm Dyform Prestressing Strand

Royals Building, London - Post Tensioned Building, UK

Applications

Bridon 7-Wire Strand is used as a prestressing element in numerous applications:-

Factory Fabricated concrete elements including sleepers, bridge beams, sign gantries, flooring, lintels, stairways and terracing. In general standard strand is used in these applications.

Post Tensioning, both internal and external, of bridges, car parks, stadiums, silos, buildings and major concrete structures such as power stations, oil platforms and LNG tanks. The properties of Superstrand lend themselves to use in this field but increasingly the demands of cost and engineering solutions are generating the use of DYFORM® Strand in post-tensioning. There has also been a move towards the use of greased and plastic coated strand as the advantages of this product in unbonded and external post-tensioning solutions has been more widely understood.

Heavy Lifts demand a product which has a very high breaking load in relation to its diameter, a property which is intrinsic to DYFORM® Strand.

Galvanised Round Wire Strand

Strand made from galvanised wires can be supplied strictly in accordance with the physical requirements of the specifications NFA35 - 035, ASTM A475 and EN 10337 standard and super grades. Electrolytic couples between the galvanised wires and other material such as ducting, reinforcement and anchorages must be prevented otherwise corrosion can be accelerated. Bridon technical personnel are available to give advice in this developing product area.

A1 Haddington to Dunbar Expressway, UK

Salford Quay, Manchester - Post Tensioned Building, UK

Prestressing Wire

Whilst specifications for Prestressing Wire are often generic, Bridon has the technical expertise to meet the exacting requirements of individual customers.

The principal use of Bridon Prestressing Wire is in stressing concrete products, primarily flooring units, lintels and beams which are extensively used in housebuilding, and small scale commercial and industrial buildings.

The standard specifications for wire have many common requirements, and those most frequently used are BS 5896, Pr EN10138 and ASTM A421. However, Bridon's technical expertise and experience lends itself to the manufacture of Prestressing Wire to a variety of standards according to customers' individual needs. These can be individually discussed.

Prestressing Wire can be manufactured with a plain finish, or with one of two patterned indents commonly known as "Belgium" and "Triple". See page 11 for technical details.

House floor "T" Beams awaiting despatch

Wire drawing prior to heat treatment

Installation of long span prestressed concrete flooring for industrial application

Bridon has made considerable investment in packaging to ensure that products are supplied with end usage in mind. All products are packaged to ensure maximum stability in transit, protection in storage and ease of use on site.

The standard package for strand, bridge wire and prestressing wire is a coil. The final presentation of the coil varies considerably between each product, and the method of dispensing individual packs also determines pack presentation:-

Prestressing Strand

Coils are layer wound for stability and ease of use and can be manufactured to over 7000kg each, but shipping and handling facilities normally restrict coil weights to the range 2000/3000kg, except when supplied in a Pentapak. Individual coils can be supplied blocked, palletised and export wrapped if required. Various methods of dispensing are available according to need.

Plastic coated strand can be presented wound on a wooden reel to provide extra protection in transit, on site and in use, or in roughwound and strapped coils.

Stay Cable Strand

Bridon has specifically designed wooden reels to accommodate Stay Cable Strand. These afford maximum stability in transit, combined with durability, and total protection for the strand while still remaining of a size and weight which allow ease of handling on site. Reels containing up to 3500kg of strand can be supplied. Each reel can be individually stencilled for ease of identity in use.

Bridge Wire

Bridon's experience in this field, and considerable investment in packaging equipment, allows the provision of a flexible package suitable for the defined individual needs of the methods employed during cable construction. Coil weights are tailored to each client's particular requirements.

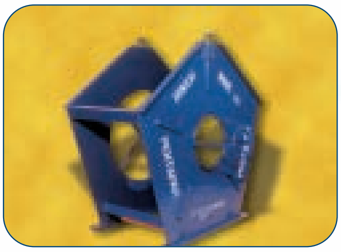
The coils are mechanically wound on specially developed blocks which control weight, outside and inside diameter, cast and lift; and are then individually wrapped by machine to provide a package which is totally suited to the rigours of export shipment, and on-site storage.

Prestressing Wire

The wire is supplied in large diameter prestraightened coils of up to 2500kg each. Coils can also be export wrapped, and are commonly supplied in weights of approximately 1000kg for this purpose.

Standard coil

Polyweave wrapped coil



UK - Pentapak dispenser

Bripak dispenser

Wooden reel used for the supply of plastic coated strand

Storage and handling on site

It must be emphasised that prestressing steel is very different from ordinary reinforcement in properties, manner of use and expected performance. Failure to observe simple precautions against damage and severe corrosion has been known to have unfortunate consequences during construction. Except for the special cases of oiled, greased and plastic covered tendons, strands are supplied dry and the surface of the steel will slowly develop a smooth film of rust which is not deleterious. If however, there is an adverse environment or the steel has to be stored on site for some time, either in coils or tendon lengths outside or in ducts, then consideration should be given to some form of protection to avoid the risk of general severe corrosion or localised pitting.

The method of storage and subsequent handling should be such that contamination, mechanical or heat damage is prevented.

The best possible protection should be given commensurate with economic cost. This will generally be met if the type of storage is sufficient to ensure that the condition of the steel, when taken out of store is no worse than the condition that will develop as a consequence of the practical procedures used during construction.

Corrosion is insignificant at relative humidities of 70% or less, although it can occur at lower humidities if there is atmospheric pollution. Procedures should be followed to minimise the possibility of condensation of moisture on the steel.

Recommendations on storage

1 If possible unload strand under cover. Do not allow the coils to be contaminated by ground conditions.

2 For short term storage outside, stack coils off the ground on timber supports covered with plastic sheeting. The area should be well drained. Cover with waterproof sheet supported on a frame over the stack so that there is no contact, and fasten down below the bottom of the coils but leave a gap at ground level.

With these precautions circulation of air within the stack will be possible, minimising the possibility of condensation of moisture, and any condensation on the underside of the cover will not be in contact with the steel. Thick clear polythene sheeting has the advantage of allowing superficial inspection of the condition of the stack without removing the cover.

3 For very long term storage outside, in addition to the above precautions, it is desirable that each coil strand is enclosed with a small bag of vapour phase inhibitor in a polythene bag or wrapping and sealed, for example by folding over the bag or top edge of the wrapping tightly and fastening down. Alternatively, the bundles or coils may be stacked off the ground on a heavy duty waterproof sheet and small bags of vapour phase inhibitor distributed in the stack which is then covered as described in (2) but with the bottom of the cover fastened down to the ground sheet to make the whole enclosure as airtight as possible. The condition of the strand should be checked periodically and the vapour phase inhibitor renewed as necessary.

4 If available, a dry, clean building provides the best storage, but for very long term storage additional precautions may be necessary depending upon climatic conditions and any atmospheric contamination. Space heating may be necessary in some months. In some countries additional enclosure as described in (3) may be necessary. Where tendons are to be in the ducts for long periods before grouting, it is usually necessary to protect them against corrosion using a water-soluble oil. Experience shows that such protective oil is flushed through or taken up in the process of grouting without any significant effect on subsequent bond.

Recommendations against damage

Prestressing strand is stressed initially to a high percentage of the ultimate strength and it is essential that the steel is not weakened by mechanical or heat damage on site.

1 Always pay out the strand from the centre of the coil by use of a dispenser or from the outside of the coil when placed on a turntable, equipped with a brake to prevent over-run of the strand.

2 Do not allow traffic to run over lengths of strand or allow any other mechanical damage, scraping or abrasion which might significantly reduce the steel section.

3 When cutting strand on site use abrasive disc cutters. If circumstances make the use of flame cutting necessary it is very important that any adjacent strand be shielded from the heat and from possible flying globules of molten metal.

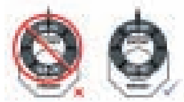
Strand which has previously been heated by an oxy-acetylene flame for no more than 5 seconds may have its strength reduced by 30% and it would fail in subsequent tensioning.

Globules of molten metal leave little or no evidence of surface damage, but in fact a semi-circular zone of brittle quenched steel structure is produced below the surface, at which point failure can be expected when the strand is tensioned. It naturally follows that any site welding or cutting operations using electric arc or flame should not be carried out near prestressing strand.

DO dry store
DO protect from impact
DO NOT expose to the elements

DO use appropriate lifting beam when transporting the strand
DO NOT use a sling or other lifting equipment

DO use correct cutters to remove straps
DO NOT cut straps until strand is loaded into the dispenser



DO load coil with front-side label to front of dispenser to avoid incorrect pay-off of strand

DO use appropriate dispenser for strand length, diameter and weight
Use of an incorrect dispenser could result in strand deformation

From leading edge product development to quality assurance, Bridon ensures that customers experience the full benefit of the technical expertise on offer. All factories operate under a complete inspection and quality control system which covers every stage of the process, and is fully approved by independent organisation.

Dimensions and properties of prestressing strand to prEN10138

Type	Nominal diameter mm	Nominal values only				Specified characteristic values		Typical values
		Tensile strength (Rm) N/mm²	Steel area mm²	Mass		Breaking load (Fm) kN	0.1% Proof load (Fp 0.1) kN	Load at 1% elongation (Ft 1.0) kN
				kg/m	m/1000kg			
standard	15.2	1670	139.0	1.090	917	232.0	204.0	204
	15.7	1770	150.0	1.170	855	265.0	228.0	233
	15.2	1770	140.0	1.095	913	248.0	213.0	218
	12.5	1770	93.0	0.726	1377	164.6	141.6	145
	11.0	1770	69.7	0.548	1825	123.4	106.0	109
	9.3	1770	53.0	0.408	2451	92.0	79.1	81
super	15.7	1860	150.0	1.170	855	279.0	240.0	246
	12.9	1860	100.0	0.781	1280	186.0	160.0	164
	11.3	1860	75.0	0.582	1718	139.5	119.8	123
	9.6	1860	54.8	0.432	2315	102.0	87.9	90
	8.0	1860	38.0	0.298	3356	70.0	61.0	62
Dyform/ compacted	18.0	1700	223.0	1.740	575	380.0	327.0	334
	15.2	1820	165.0	1.290	775	300.0	258.0	264
	12.7	1860	112.0	0.875	1143	209.0	238.0	184

Dimensions and properties of single wires for prestressed concrete to prEN10138

	Nominal			Specified characteristic values		Typical values	Tensioning loads @			
Nominal diameter	Tensile strength (R_m)	X-sect. area (S_n)	Mass (M)	Breaking load (F_m)	0.1% Proof load ($F_{p0.1}$)	Load 1% elong'n ($R_{t1.0}$)	65% of GUTS	70% of GUTS	75% of GUTS	80% of GUTS
mm	N/mm²	mm²	g/m	kN	kN	kN	kN	kN	kN	kN
7	1570	38.5	300.7	60.4	53.2	51.3	39.3	42.3	45.3	48.3
7	1670	38.5	300.7	64.3	73.9	54.7	41.8	45.0	48.2	51.4
6	1670	28.3	221.0	47.3	54.4	40.2	30.7	33.1	35.5	37.8
6	1770	28.3	221.0	50.1	44.1	42.6	32.6	35.1	37.6	40.1
5	1570	19.6	153.1	30.8	27.1	26.2	20.0	21.6	23.1	24.6
5	1670	19.6	153.1	32.7	28.8	27.8	21.3	22.9	24.5	26.2
5	1770	19.6	153.1	34.7	30.5	29.5	22.6	24.3	26.0	27.8
4.5	1620	15.9	124.2	24.8	29.7	21.1	16.1	17.4	18.6	19.8
4	1670	12.6	98.4	21.0	24.2	17.9	13.7	14.7	15.8	16.8
4	1770	12.6	98.4	22.3	19.6	19.0	14.5	15.6	16.7	17.8

GUTS=Grade Characteristic Breakload (F_m)
Maximum relaxation after 1000 hours for % characteristic breaking load: 60% = 1%, 70% = 2.5%, 80% = 4.5%

A comparison of the respective properties of conventional and Stay Cable Strand

Property	Conventional Prestressing Strand	BRIDON Stay Cable Strand
Fatigue to 2 x 10⁶ cycles		Plain & galvanised
Stress range	200N/mm²	300N/mm²
Maximum load	70%	45%
FIP deflected tensile test		Plain & galvanised
Maximum reduction in load (D)	28%	20%
FIP stress corrosion		galvanised only
Minimum lifetime to failure	1.5 hours	4 hours
Mean lifetime to failure	4.0 hours	12 hours

From leading edge product development to quality assurance, Bridon ensures that customers experience the full benefit of the technical expertise on offer. All factories operate under a complete inspection and quality control system which covers every stage of the process, and is fully approved by independent organisation.

Tolerances

Diameter 12.5mm and larger :+0.4 – 0.2mm
11.0mm and smaller + 0.3 – 0.15mm
Steel area and mass + 4% - 2%
Elongation is not less than 3.5% at fracture on a gauge length of 500mm minimum
Relaxation: all strands supplied with low relaxation characteristics (Class 2).

Other Strands

9.3mm/indented – made from indented wires for use in sleepers.
15.4mm/250kN minimum breaking load.
15.5mm/261kN minimum breaking load.

Greased and plastics covered strand

The Bridon protection process is in three stages:

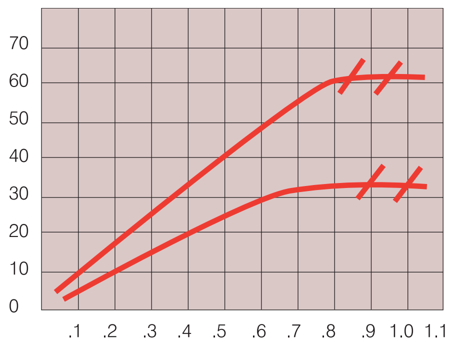
- application of a protective fluid which penetrates to the centre wire of the strand
- coating of the strand with a highly corrosion-resistant special grease
- continuous hot extrusion of a high density polypropylene or polyethylene sheath over the strand.

The grease gives long term protection and lubrication for ease of movement when stressing the strand. It is water free, typically 130 C drop point, retains workability down to -30 C, is highly corrosion resistant and completely non-hazardous.

The polypropylene or polyethylene sheath is a premium grade copolymer, stabilised with finely divided and dispersed carbon black providing the following significant advantages:

- very high stability in respect of U.V. degradation
- high dimensional stability at elevated temperatures
- excellent impact resistance even at sub-zero temperatures
- high-rigidity – will not collapse in service
- excellent crack resistance
- excellent chemical resistance
- high resistance to abrasion and creep
- easily repairable on site should damage occur
- complies fully with FIB recommendations.

The nominal radial thickness of the sheath can vary between 0.75mm and 3.00mm depending on strand size and use. Laser measurement devices ensure consistency of sheath thickness. Although the plastic cover is able to withstand some abuse, care is necessary when placing and stressing tendons to minimise damage.



Single wires

Quality Assurance

Bridon factories operate under a complete inspection and quality control system detailed in a Quality Manual. This defines all the controls at every stage from rod to finished product and includes procedures for control of auxiliary site services, calibration of recording equipment and internal audit of the system in line with ISO 9001.

The Quality control system is investigated and approved by a number of independent organisations, including independent checking of mechanical properties and testing procedures.

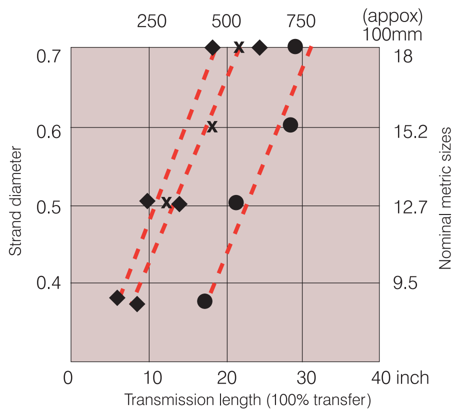
ISO 9001 approval is an integral part of Bridon's total quality strategy and is independently certified by the technical approval bodies of BSI and CARES.

Transmission Lengths

Tests have been reported on the bond characteristics or transmission lengths of Bridon round wire strand and DYFORM® Strand. Tests were made with prestressed beams approximately 3m long and 34 x 18cm section and a concrete strength at transfer in the range of 56 to 65 n/mm2. The initial stress in the strands was 75% of the specified characteristic strength.

Transmission length determinations were made in the manner described in earlier Research Reports of the Cement & Concrete Association and the average results are shown (below) graphically in comparison with earlier C. & C.A. results using round wire strand and initial stress of 70% of specified strength.

Because of the smoother surface configuration of DYFORM® Strand and its greater initial force compared with round wire strand, a larger transmission length for 100% transfer of stress is to be expected. The relationship is approximately proportional, for standard grade round wire strand the transmission length is about 30 strand diameters and for DYFORM® Strand about 45 strand diameters.

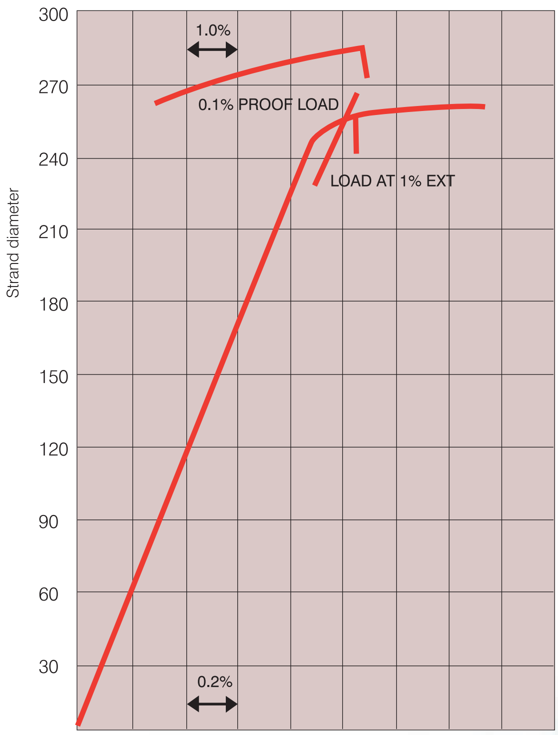


Load Extension

A typical load extension graph is shown to the right.

The graphs are recorded autographically up to the fracture of the test piece using a non-contact extensometer, which operates by photo-electric cells following the movement of illuminated white gauge marks on the test piece as the latter extends under increasing load in the tensile testing machine. Electrical impulses for load and extension are fed into the recorder. In the elastic and early plastic range of extension a high magnification is used for extension. In the later stage, up to fracture, the extension recording is switched back to a lower magnification to accommodate the total extension on a normal size graph paper. The two magnifications are shown as percentage extensions on the graph grid.

Typical load extension graph



Effect of Deflection on Strand Properties

From time to time tests have been made to note the effect of various forms of deflection on the properties of round wire strands and DYFORM® Strands.

Deflection at Pins and Saddles

In deflection from a straight line through a triangular three point system, if the ratio of pin/strand diameter is very small, there is a significant reduction in the strength of the strand, but the effect can be reduced if the angle of deflection is small. Where the deflection is round a saddle of significantly larger diameter than the strand, the loss in strength is small and the larger the ratio of diameters, the larger the possible angle of deflection without loss of strength.

Strand deflected over an adjacent strand

Lengths of DYFORM® Strand stressed diagonally over another piece of the same diameter strand, with an angle of deflection of 3º at the cross-over point had strengths of 99 to 100% of the normal actual strength, but in two out of three tests the wire failures occurred at the deflection point.

Strand deflected through 180º

Tests have been made on strands deflected round capstans through an angle of 180º. In loading test to failure, the breaking load was over 90% of the actual strand strength where the capstan diameter was 8 x strand diameter and over 96% where the capstan diameter was 16 x strand diameter. In an examination of the effect of bending on properties, strands have been fixed in the curved position for 7 days under a load of 70% of the breaking load and then tested after release in the straight condition. Where the capstan diameter was 10 x strand diameter, breaking load had not been affected, but 0.1% and 0.2% proof loads were reduced by about 5%. With capstan diameters of 120 and 150 x strand diameter subsequent tests did not show any adverse affect on any properties.

Cyclic loading at a point of deflection

DYFORM® Strand deflected through an angle of 10º over a pin diameter 1.5 times the strand diameter has endured without failure 300 oscillations of load between 6.4% and 63.9% of actual strand strength, at a rate of about 3 oscillations/minute. See table below.

Deflector/strand diameter	Angle of deflection	Strength % of normal	Strength % of normal
1.0x	3º	99 - 100*	Simple
1.4x	10º	76	Triangular
	5º	88 - 90	Triangular
1.75x	10º	70 - 88	Triangular
10.0x	5º	95 - 99	Triangular
12.0x	5º	95 - 98	Triangular
50.0x	10º	100	Triangular

*Strand deflected over an adjacent strand

At the end of the test the strand was examined. There was slight marking where there had been contact with the pin and there was a permanent bend in the strand.

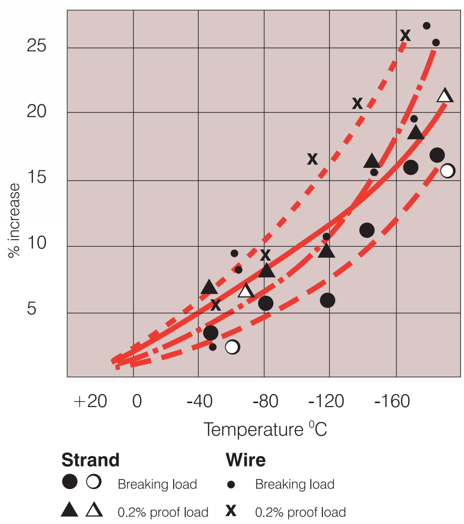
Wire and strand properties at cryogenic temperatures

The behaviour of cold drawn carbon steel at very low temperatures is generally satisfactory, except that there is a reduction in constriction at failure.

Tests on BRIDON products have been made at between -60° C and -190° C with test pieces and prestressing grips completely contained within the cold zone. Testing carried out at Munich University.

Control tests were made at normal temperature. The pattern of behaviour confirms the evidence of other investigators and a summary of information on ultimate strength of 0.2% proof stress is given in the graph, expressed as percentage change from the normal temperature values. The 0.01% and 0.1% proof stress values show similar increases as the test temperature falls. Resistance to fatigue does not seem to be much affected and, as might be expected, relaxation losses are negligible at low temperatures.

The reduction in ductility is variable. In wire tests at -60° C the constriction at the tensile fracture is 5% to 14% less than the normal temperature result and 20% to 60% less at -190° C. The elongation, measured after fracture in 250mm, shows a loss of 30% to 50%. At -190° C strand elongation, measured to fracture in 600mm, shows a similar loss, but in tests using prestressing wire and strand grips there is a greater tendency for fracture to occur at the grip at the low temperatures and some of the apparent loss in elongation can be attributed to breaks at grips. For example DYFORM® Strand tested with testing machine wedges at normal temperature had an elongation of 7%, but in prestressing strand grips failure occurred at the grip and in consequence the elongation was about 35% lower at -190° C the result was still 4.5% i.e. there was no further loss in elongation at the low temperature.



Relaxation

BRIDON has had a specially equipped relaxation testing laboratory for many years and tests are regularly made. The graphs summarise much of the work and the notes pick out some practical points.

Test method

The procedure is in accordance with national and international specifications. Loss of load is recorded indirectly by change of strain in a calibrated deflection beam. In elevated temperature tests the test piece is heated to the required temperature in the unloaded condition and maintained at temperature for at least 20 hours to establish stability throughout the test system, before the initial load is applied.

Relaxation loss is plotted against time on logarithmic scales. A linear relationship develops on the graph after a few hours on the time scale and this linearity has been proved in tests on normal relaxation wire and on low relaxation strands for periods of over 11 years (100,000 hours). Although tests of 1000 hours duration are usual, tests of 200 hours or only 72 hours are sufficient for many purposes and the plots can be extrapolated to 1000 hours.

Practical interpretation of test results

Laboratory tests are carried out under arbitrary standard conditions of loading at a constant temperature (20° C) and test length. The initial load, for quality control purposes, is related to the actual strength of the product.

In construction, initial loads are related on specified characteristic strength, loading rates may be faster, temperature will vary, creep of concrete and other effects will permit reduction in the initial load in the early stages. During the life of the structure parts may be subject to significant rises in temperature, for example in bridge decks and in pressure vessels.

Effect of diameter

The size of the product is not significant in relaxation behaviour; it is the type of final treatment of the 7-wire strand, for example, which determines whether the product has normal or low relaxation characteristics.

Effect of loading rate

A fast loading rate in practice will cause short term difference in relaxation, for example with low relaxation strand the 1000 hour loss of load will be about 0.3% higher if the load is applied in 3 minutes, compared with a long time of 10 minutes, but over a very long period this initial effect is insignificant.

Effect of magnitude of load

The strand average 1000 hour relaxation losses as percentage of initial load are of the order of figures shown in the table.

Initial load Actual strength	75%	70%	65%	60%
Low rotation % loss	1.6	1.1	1.04	1.0
Normal relaxation % loss	7.6	5.6	4.4	3.4

When making comparisons it should be remembered that the percentage losses are related to different percentage initial loads, for example in terms of force the 1.0% loss from 60% of the actual strength is only half the loss of 1.5% from 75% of actual strength. Obviously a small loss of force due to other construction factors in the very early stages would not have much effect on the subsequent relaxation of low relaxation strand. In units of force the 1000 hour loss from 65% is 88% of the loss from 70% actual strength.

With normal relaxation strand, the corresponding loss would be about 75% of the loss expected from 70% of the actual strength.

The fact remains that the loss for low relaxation strand is only about one fifth of the loss for normal relaxation strand.

Effect of temperature

Where a considerable part of the working life will be at temperatures higher than 30° C low relaxation strand is preferred. The low relaxation product should not be used at temperatures higher than 80° C unless the working loads are significantly reduced.

The limited evidence of two stage tests at 20° C and 60° C indicates that the total long term behaviour will be little different from the relaxation occurring entirely at the elevated temperature.

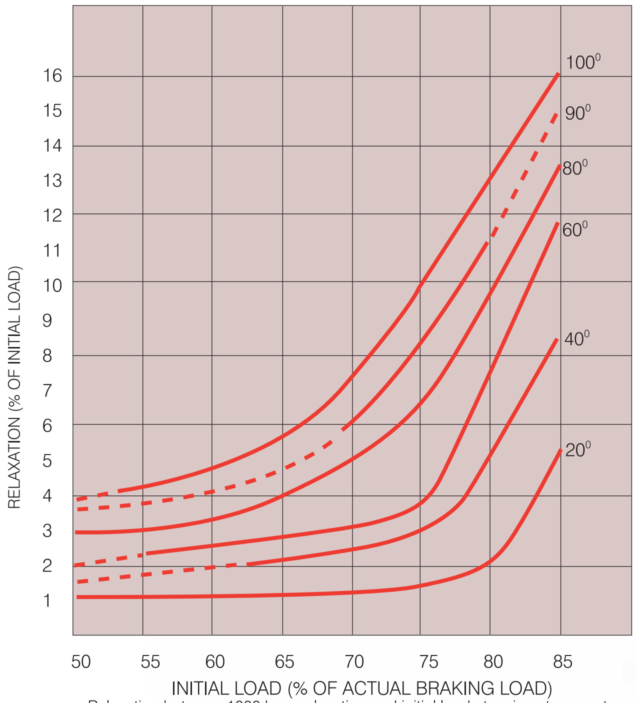
Estimation of long term relaxation

As indicated under test methods linearity of the relaxation graph on log-log scales has been proved up to 100,000 hours and there is no reason to suppose that the relationship will change in the next part cycle on the log-time scale up to 500,000 hours.

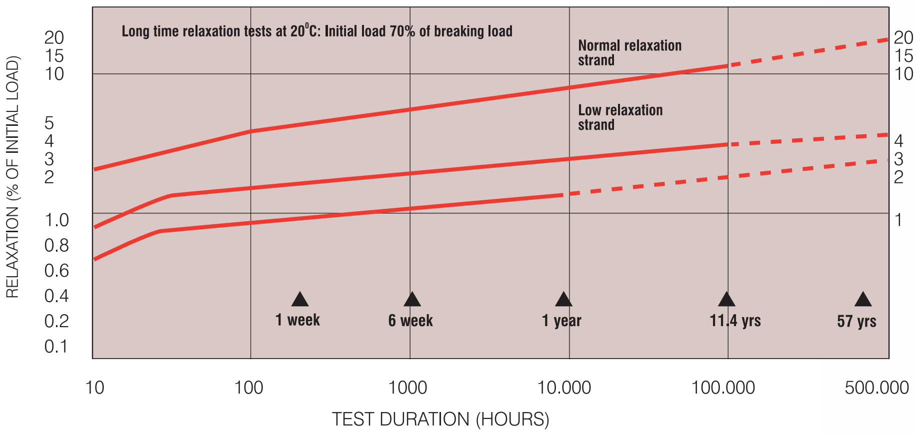
In tests on strand at 20° C and an initial load of 70% of strand strength, the evidence from short time tests is that the 500,000 hour (57 years) relaxation will average 1.8 x 1000 hours loss for the low relaxation product and about 3 x 1000 hours loss for normal relaxation strand.

Extrapolations from 10,000 and 100,000 hours tests show a 500,0000 hours loss of 1.5 x 1000 hours loss for low relaxation strand and 2.6 x 1000 hours loss for normal relaxation strand.

In practice these factors may be reduced to take into account other factors which reduce the initial load.



Relaxation between 1000 hour relaxation and initial load at various temperatures



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