

# BBR HiAm CONA

Strand Stay Cable System

## Elegance and Strength

The extended HiAm CONA family



A Global Network of Experts  
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# BBR A Global Network of Experts

www.bbrnetwork.com

The BBR Network is recognized as the leading group of specialized engineering contractors in the field of post-tensioning, stay cable and related construction engineering. The innovation and technical excellence, brought together in 1944 by its three Swiss founders – Antonio Brandestini, Max Birkenmaier and Mirko Robin Ros – continues, more than 60 years later, in that same ethos and enterprising style.

From technical headquarters in Switzerland, the BBR Network reaches out around the globe and has at its disposal some of the most talented engineers and technicians, as well as the very latest internationally approved technology.

## THE GLOBAL BBR NETWORK

Within the Global BBR Network, established traditions and strong local roots are combined with the latest thinking and leading edge technology. BBR grants each local BBR Network Member access to the latest technical knowledge and resources – and facilitates the exchange of information on a broad scale and within international partnering alliances. Such global alliances and co-operations create local competitive advantages in dealing with, for example, efficient tendering, availability of specialists and specialized equipment or transfer of technical know-how.

## ACTIVITIES OF THE NETWORK

All BBR Network Members are well-respected within their local business communities and have built strong connections in their respective regions. They are all structured differently to suit the local market and offer a variety of construction services, in addition to the traditional core business of post-tensioning.

## BBR TECHNOLOGIES

BBR Technologies have been applied to a vast array of different structures – such as bridges, buildings, cryogenic LNG tanks, dams, marine structures, nuclear power stations, retaining walls, tanks, silos, towers, tunnels, wastewater treatment plants, water reservoirs and wind farms. The BBR brands and trademarks – BBR®, CONA®, BBRV®, HiAm®, DINA®, BBR E-Trace® and CONNAECT® – are recognized worldwide.

The BBR Network has a track record of excellence and innovative approaches – with thousands of structures built using BBR Technologies. While BBR's history goes back to 1944, the BBR Network is focused on constructing the future – with professionalism, innovation and the very latest technology.

BBR VT International Ltd is the Technical Headquarters and Business Development Centre of the BBR Network located in Switzerland. The shareholders of BBR VT International Ltd are BBR Holding Ltd (Switzerland), a subsidiary of the Tectus Group (Switzerland) and KB Spenneteknikk AS (Norway), a subsidiary of the KB Group (Norway).

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# Robust Experience

The BBR Network's experience with stay cable technology reaches back over six decades and our portfolio features over 430 cable-stayed projects around the world. Although BBR is mostly famous for wire stay cables, we were actually also the inventors of strand and carbon stay cables – and carried out the world's first projects using high fatigue resistant wire, strand and carbon stay cables.

The further evolution of BBR technology has seen the creation of many ground-breaking structures, such as the cable-net supported roof of the 1972 Olympic Stadium in Munich, Germany and the cable-stayed Sydney Tower in 1981, both of which have become cultural icons while still serving their original purpose.

The constant focus on R&D and technology development at BBR Headquarters in Switzerland means that, today, the BBR Network continues to lead the way in both stay cable technology and techniques for its application.

## How to use this brochure



### Stay Cable references

Over 50 years and more than 430 projects.



### BBR VT CONA CMX

The most advanced strand PT system.



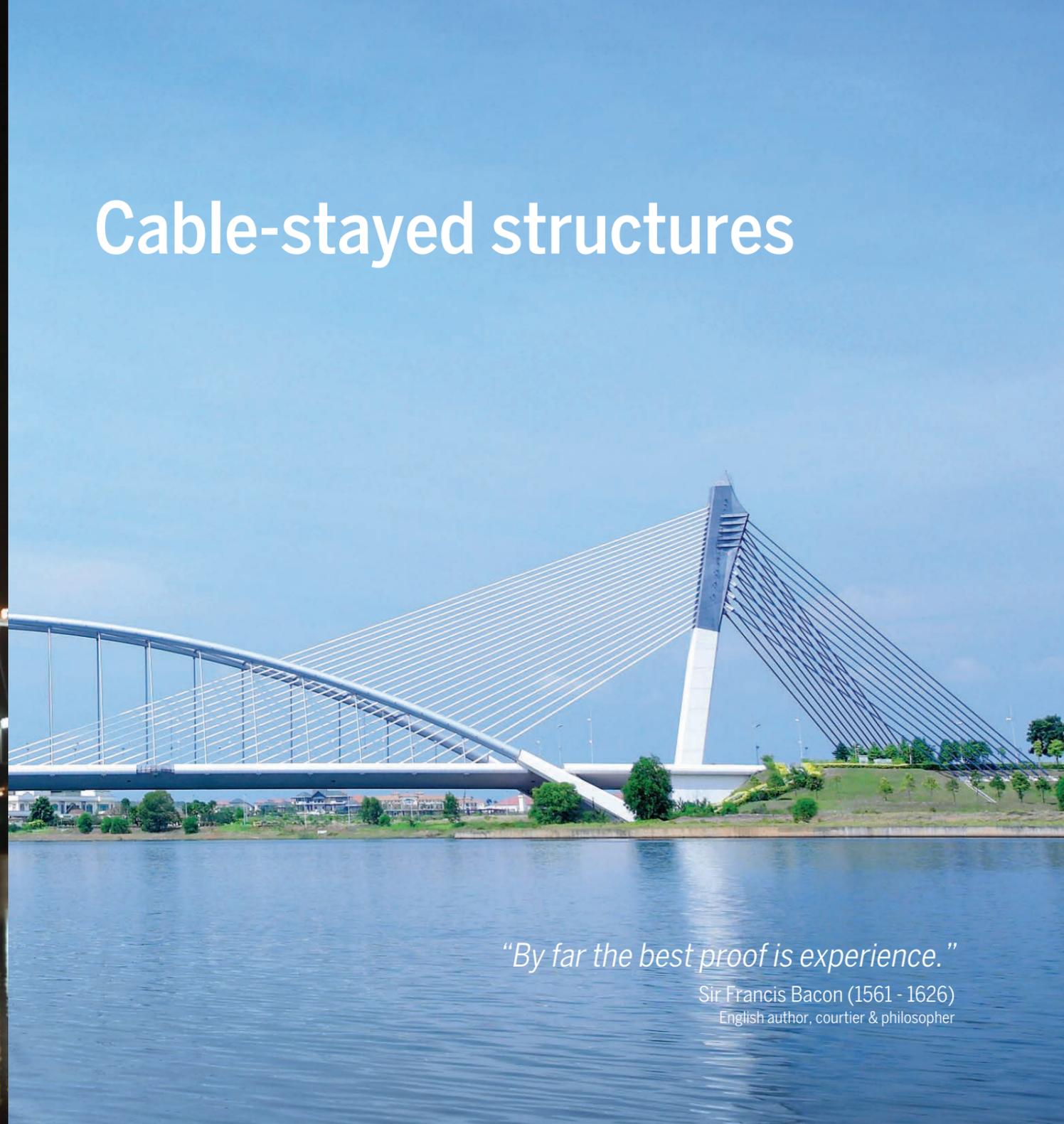
### CAD drawings & 3D models

CAD files and 3D models of BBR systems.

Go to [www.bbrnetwork.com](http://www.bbrnetwork.com) to download these brochures and check the available information.

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# Cable-stayed structures



*"By far the best proof is experience."*

Sir Francis Bacon (1561 - 1626)  
English author, courtier & philosopher

What is the first thing that you think about when you see a cable-stayed structure? Is it perhaps the strength of the technology supporting that structure – or maybe it is the sheer elegance that stay cables bring to the landscape or city skyline?

Some of the most dramatically beautiful architectural designs and technically excellent feats of engineering provide a reliable service, on a daily basis, to thousands of people around the world. Many of these creations have been realized with the use of BBR Technologies. ›



## Stay cable introduction

BBR Stay Cable Technology has been applied to over 430 major structures around the world. While many cable suppliers built their first major cable supported structure in the late 1970s and early 1980s, BBR Stay Cable Technology was used for the first time in the late 1950s and, since those days, BBR has followed on with milestone-after-milestone and continues to set the standard in the field of stay cables.

### Stayed applications

BBR Stay Cable Technology can be used for the following applications:

**Cable-stayed bridges** – built in rapidly increasing numbers since 1950 and especially suitable for medium- to long-span bridges from 100 to 1,000 m, where technical and economic factors dictate this solution. For smaller bridges, other parameters may be decisive in the choice of a cable-stayed solution – such as reduced depth of deck, construction methodology and aesthetics. BBR Stay Cable Technology is the ideal choice for the cables.

**Arch bridges** – where BBR Stay Cable Technology is the solution of choice for the hangers.

**Roofs** – of grandstands, stadiums, aircraft hangars and other lightweight wide-span structures are an ideal application for BBR Stay Cable Technology.

**Towers** – for communication facilities, chimneys and antennas, as well as wind power stations can be stabilized using BBR Stay Cable Technology.

### Temporary applications

Despite being designed to have a longer service life, BBR HiAm CONA stay cables have been successfully used for many temporary applications due to its flexibility, robustness and high resistance to fatigue.

For decades, BBR has offered the very best, state-of-the-art technology for cable stayed structures and today this is backed by over 75 years of specialist technical know-how.



Photo: Kevin Lazarz

### International specifications

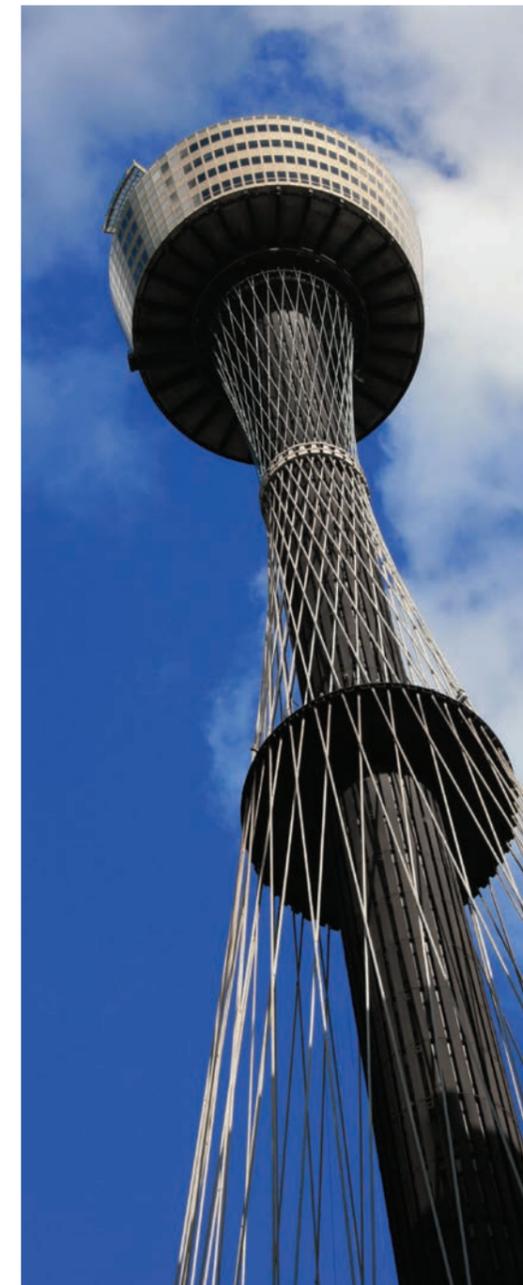
Specifications for stay cables have, in the past, always been covered by guidelines and recommendations, historically the most popular has been **PTI – Post-tensioning Institute (USA), Recommendation for Stay Cable Design, Testing and Installation.**

There are other less common and minor national recommendations such as, for example, from CIP(Setra) in France. National recommendations cover only locally available materials and construction practices and are limited to the knowledge of local suppliers, which lead to an unjustified and incorrect treatment of stay cable systems as a whole. To ensure international and legally correct tenders, such national recommendations

should not be considered – they may occasionally only be used as complementary guidelines. Today, the state-of-the-art and internationally versatile recommendation is **fib – International Federation for Structural Concrete, Bulletin 89, Acceptance of Stay Cable Systems using Prestressing Steels.**

### Importance of high fatigue resistance

Stay cables are subjected to high tensile forces and, given the fact that cable supported structures are typically very light structures, the stay cables are subjected to high stress variations, thus high fatigue resistant stay cables are of great importance. ›





#### Typical loadings of a stay cable

Besides maximum axial stresses in a stay cable under service conditions, ultimate state conditions and fatigue loadings, a series of other loads must be considered at the design stage – these include construction loads, accidental loads and bending effects. An additional factor is the durability of stay cables and the most modern stay cable systems have been developed and tested (*fib*) with provisions leading to an intended working life of the stay of 100 years and more.

#### Research & development

Extensive research, testing and development efforts place BBR at the forefront in the field of post-tensioning and stay cable applications. To assure the highest quality product, all of the system components are subjected to the most stringent testing and quality assurance procedures, based on internationally recognized codes and recommendations.

#### Beware of imitations

There has been much talk about counterfeit components – copies of BBR Stay Cable Technology which ultimately risk lives and do not guarantee the required performance for the owners. There are indeed many stay cable systems on the market which, despite some of them looking very much like BBR systems or even bearing our trademarks, they actually have no relation to the original and genuine BBR Technology. For stay cables, it is not only the technology itself which has to fulfill the highest requirements of design, manufacturing and quality control, but also the installation of the cables on site must conform to these standards and be executed only by trained professionals. If you are in any doubt about a product or service which is offered, seek advice from BBR VT International Ltd. •



## Benchmark for test performance

BBR Stay Cable Systems are the benchmark in terms of test performance and BBR Stay Cable Technology has regularly fulfilled higher testing and performance criteria – even years before such testing conditions have been adopted and specified in codes and recommendations. ›



BBR HiAm CONA Pin Connector



Saddle test with BBR HiEx CONA

# BBR HiAm CONA Stay Cable

## Successful testing with BBR HiAm CONA

### Tests according to standards

Impressive evidence of the leading role of BBR in relation to testing are the tests executed successfully on the BBR HiAm CONA Strand Stay Cable System:

- Axial fatigue and subsequent tensile test according to CIP (Setra) and *fib*, with a stress range of 200 MPa and an angular rotation of 0.6° at the anchorages on various anchorage sizes, even on a huge 127 strand BBR HiAm CONA cable.
- Leak tightness test according to *fib* with axial, rotational and temperature cycles, while BBR HiAm CONA is the only system where the sealing can be replaced on an individual basis as part of single strand replacement operations.
- Axial fatigue and subsequent tensile test according to CIP(Setra) for extradosed applications using saddles with a stress range of 140 MPa and an upper load of 55% GUTS.
- Bending fatigue test according to *fib*, with applied rotations at the anchorages of 2.8° and 1.2° for 2.0 million and 0.1 million cycles respectively.
- Static as well as axial fatigue and subsequent tensile test according to *fib* on the BBR HiAm CONA Pin Connector.

### Going the extra mile

The leading position of BBR is particularly highlighted by the tests, recently executed, with parameters exceeding the traditional requirements of *fib* and PTI. The following is a selection of benchmark tests carried out successfully on the BBR HiAm CONA System:

- Long term axial fatigue tests for stay cables and extradosed cables. For stay cables an axial stress range of 200 MPa with an upper load of 45% GUTS and for extradosed cables an axial stress range of 140 MPa with an upper load of 55% GUTS.
- Axial fatigue and subsequent tensile tests where upper loads and stress ranges exceed the commonly specified 200 MPa stress range and 45% GUTS upper load. In such fatigue tests, we achieved a 300 MPa fatigue resistance and 55% GUTS upper load.
- Multi-million cycle wear and durability test on BBR Square Damper, proving the endurance and minimal maintenance requirements of this advanced damper.
- BBR Square Damper efficiency test with cable tensions ranging from 25% to 45% GUTS in 1<sup>st</sup> to 5<sup>th</sup> modes, on a BBR HiAm CONA stay cable model representing a 500 m cable length. This test is especially noteworthy as cables of this length with low tension experience second order effects due to large sag, which makes many common dampers ineffective – not so the BBR Square Damper.

Obviously, the tests have been executed with strands of the highest tensile resistance available on the market – strands with a resistance of 1,860 MPa with a cross section of 150 mm<sup>2</sup> and a breaking strength of 279 kN. For higher strength strand please contact your nearest BBR representative. Many stay cable suppliers still work with strands of 1,770 MPa capacities or cross-sections of 140 mm<sup>2</sup>. Compliance tests for such lower capacity strands have naturally also been executed on the BBR HiAm CONA System. •

### Key Benefits

- Tendon capacity 200 – 60,000 kN
- Superior fatigue resistance
- Advanced water tightness system
- High corrosion protection
- Compact anchorage and cable
- Single strand installation and replacement
- Easy and low maintenance

The BBR® HiAm® CONA® Parallel Strand Stay Cable System is the best product on the international market place. It has the highest capacity, most compact and widest range of anchorages available. Developed, tested and continuously maintained by BBR engineers in Switzerland, the BBR HiAm CONA Parallel Strand Stay Cable System is being used by the BBR Network around the world. Combined with the installation expertise of the BBR Network – backed by the Engineering and Special Projects Team from the Swiss BBR Headquarters – this system is simply unrivaled anywhere on the planet. ›



## Key features

### Strong & sleek

Its superior fatigue resistance – ‘HiAm’ stands for high amplitude fatigue resistance – makes it attractive for the most challenging of projects and thus it appeals to engineers and clients alike. Designers and architects have welcomed, in particular, the compactness of the anchorage and cable system, as it allows them greater scope to produce a structure which has sleeker lines and which appeals to the visual senses of all who use and gaze upon it.

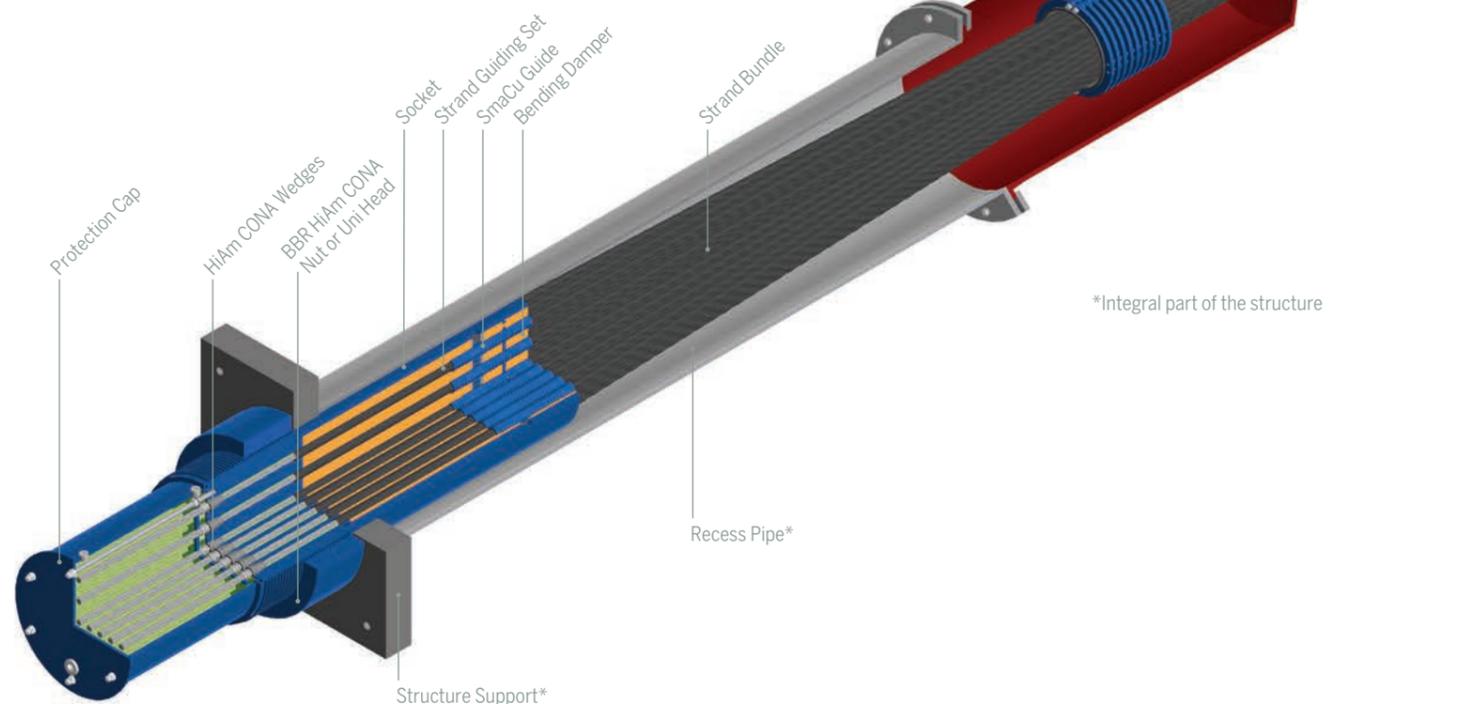
### Local knowledge – international expertise

The BBR HiAm CONA Stay Cable System is exclusively installed by teams of certified BBR Stay Cable Specialist Companies. Cable-stayed bridges are highly-specialised engineering projects, requiring local know-how and specific engineering knowledge. Therefore the local project management is typically handled by the local BBR Network Member, while all stay cable specification, engineering system component manufacturing and procurement is handled by the Special Projects Team from the Swiss-based BBR Headquarters.

### Stay cable configuration

BBR HiAm CONA cables are made up of a compacted bundle of a predetermined number of parallel seven-wire strands enclosed in a co-extruded (carbon black internal and colored external) ultra-violet resistant high-density polyethylene (HDPE) sheath of circular cross-section. The individual strands generally have a diameter of 15.7 mm (0.62”), are of low relaxation grade, with nominal cross-sectional area of 150 mm<sup>2</sup> and a minimum Guaranteed

Ultimate Tensile Strength (GUTS) of 1,860 MPa. For higher strength strands please contact your nearest BBR representative. The strands are galvanized, corrosion inhibited and individually sheathed with a continuous and wear resistant HDPE coating, providing each strand with an individual multilayer protection system with three nested barriers. Alternatively, coated strands with a corresponding corrosion protection system may also be used (such as epoxy coating).

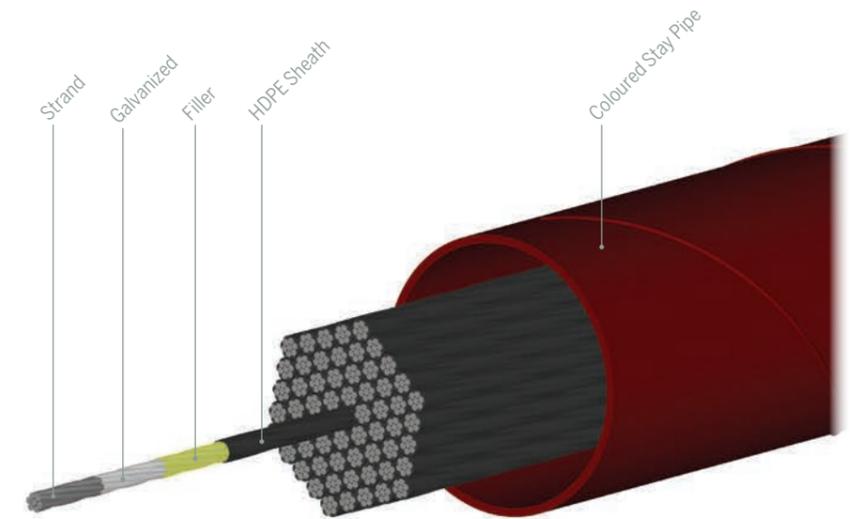


### Certification

The BBR HiAm CONA Stay Cable System is deemed approved and in compliance with the *fib* as well as the corresponding PTI and CIP(Setra) recommendations.

### Bending damper & countering cable vibration

In the socket of the anchorage, each strand is individually protected with a proprietary bending damper. Bending effects in cables may be introduced from excessive construction tolerances, structure deflections/rotations and cable vibrations. Supplemental internal or alternatively external high damping devices protect the stay cable from vibrations. Another effective countermeasure against wind and rain-induced vibrations is the use of a helical rib on the outside of the cable surface.



### Anchorage configuration

Near the anchorage zone of the BBR HiAm CONA cables, the strand bundle passes a deviator and spreads out towards the BBR HiAm CONA socket, where each strand is individually guided, sealed leak tight and locked in the anchor heads with specially designed high fatigue resistant BBR HiAm CONA wedges. Ring nuts screwed onto the anchor heads transfer the cable loads by contact pressure onto the supporting structure. Alternatively, the anchor heads may transfer the loads directly to the structure. All anchorage components of the BBR HiAm CONA System have been designed for a stress range greater than 300 MPa and to withstand the ultimate breaking load of the strand bundle with adequate safety.

### Installation

The installation of the BBR HiAm CONA System is typically performed on site using the strand-by-strand installation method, which is comprised of four basic steps:

- Installation of the upper (pylon) and lower (deck) HiAm CONA anchorages.
- The preassembled stay cable sheath is hung between the two anchorages using two master strands. The stay cable sheath is now used as a guide passage from anchorage-to-anchorage.

- The strand is positioned at deck level and pulled up through the stay pipe and the upper anchorage and inserted into the lower anchorage.
- Each strand is tensioned immediately after installation, using the BBR ISOSTRESS tensioning method, ensuring an equal stress distribution among the strands of an individual cable.

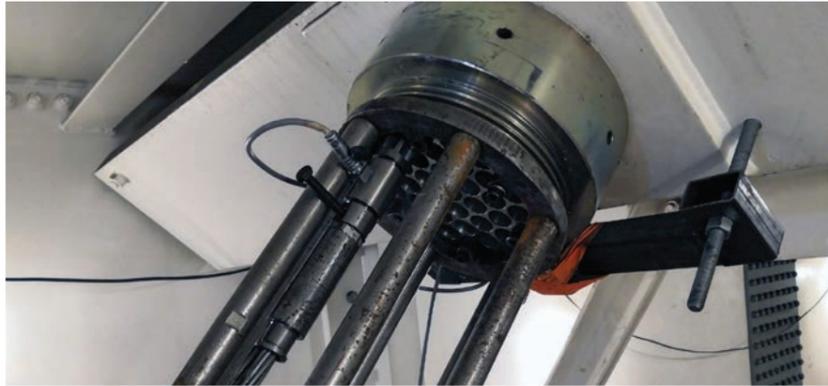
Alternatively to the single-strand installation method, fully or partially prefabricated cables can be installed and tensioned. ›

### Strand-by-strand restressability and replacability

The tendon or each individual strand installed in the BBR HiAm CONA Cable System can be re-stressed at any time during or after the installation, allowing not only for a re-stressing, but also for the selective removal, inspection, replacement or addition of individual strands without compromising the integrity of the overall corrosion protection system.

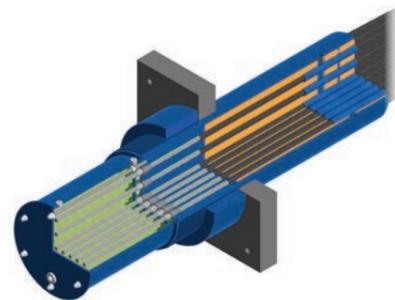
## HiAm anchorage options

The end of the stay cable from which the tensioning is performed – the stressing end of the cable – is fitted with adjustable BBR HiAm CONA Nut Head anchorages and the opposite end, or the dead end of the cable, is typically fitted with BBR HiAm CONA Uni Head anchorages or BBR Pin Connectors, see page 16 and 17.



### BBR HiAm CONA Nut Head anchorage:

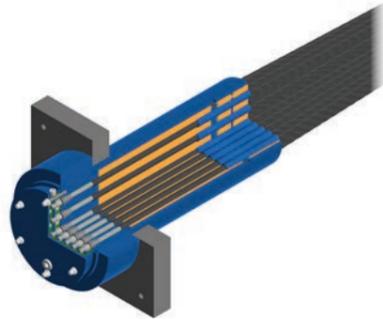
Adjustable anchorage, with a typical adjustability of 0, 60 or 120 mm. The adjustability can be modified to accommodate any regulation specification. This anchorage is required at the stressing end of the cable and may also be required at the dead end anchorage if fully prefabricated cables are installed – or if the anchorage detail in the structure does not permit an installation of the anchorage from the back face of the bearing plate.



BBR HiAm CONA Nut Head anchorage 120\* mm adjustability

### BBR HiAm CONA Uni Head anchorage:

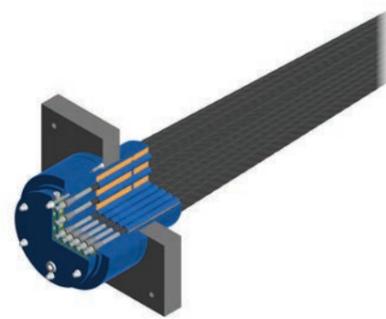
Non-adjustable anchorage with identical key dimensions compared to the BBR HiAm CONA Nut Head anchorage with 0 mm adjustability. This anchorage should be used if the same anchorage details at the deck and pylon are desired and if the anchorages can be installed from the back face of the bearing plate.



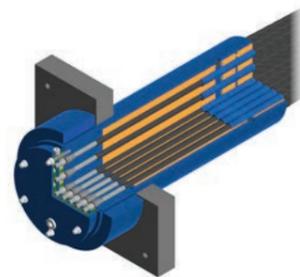
BBR HiAm CONA Uni Head non-adjustable anchorage

### BBR HiAm CONA Uni Head Short Socket anchorage:

Non-adjustable anchorage used for the dead-end of the stay cable. The anchorage is the perfect solution where accessibility is limited, offering an even more compact and cost effective solution without any reduction of performance.



BBR HiAm CONA Uni Head Short Socket non-adjustable anchorage



BBR HiAm CONA Nut Head anchorage 0 mm adjustability

\*length of adjustability can be customised to each individual cable.

### Standard configuration

The standard configuration of the adjustable and dead anchorage requires identical openings in the bearing plate – thus, if the structure is designed with this philosophy and assumptions, the stressing and the dead end orientation of the cable is interchangeable at any time during the design stage of the cable-stayed structure.

### Compact configuration

In addition to the standard configuration, a Compact version is offered for both the BBR HiAm CONA Nut Head and the BBR HiAm CONA Uni Head anchorage. The Compact version suits smaller openings in the bearing plate, compared to the standard configuration. All Compact BBR HiAm CONA anchorages require installation from the back face of the load transfer element.

## Transition length options

In the anchorage zone of the BBR HiAm CONA Stay Cables, the strands are bundled at the deviator and within a transition length spread out towards the BBR HiAm CONA socket. Depending on the chosen configuration – guide deviator, free deviator or damper – different transition lengths are required.

### Guide deviator

Guide deviators have historically been used, with good experience, to support the stay cable laterally and to limit transverse displacements of the stay cables. As a consequence, they protect anchorages from the effects of transverse loads, which are transferred into the structure at the location of the guide deviator. When using a guide deviator, the minimum required transition length is denoted by GDL, see pages 14 and 15.

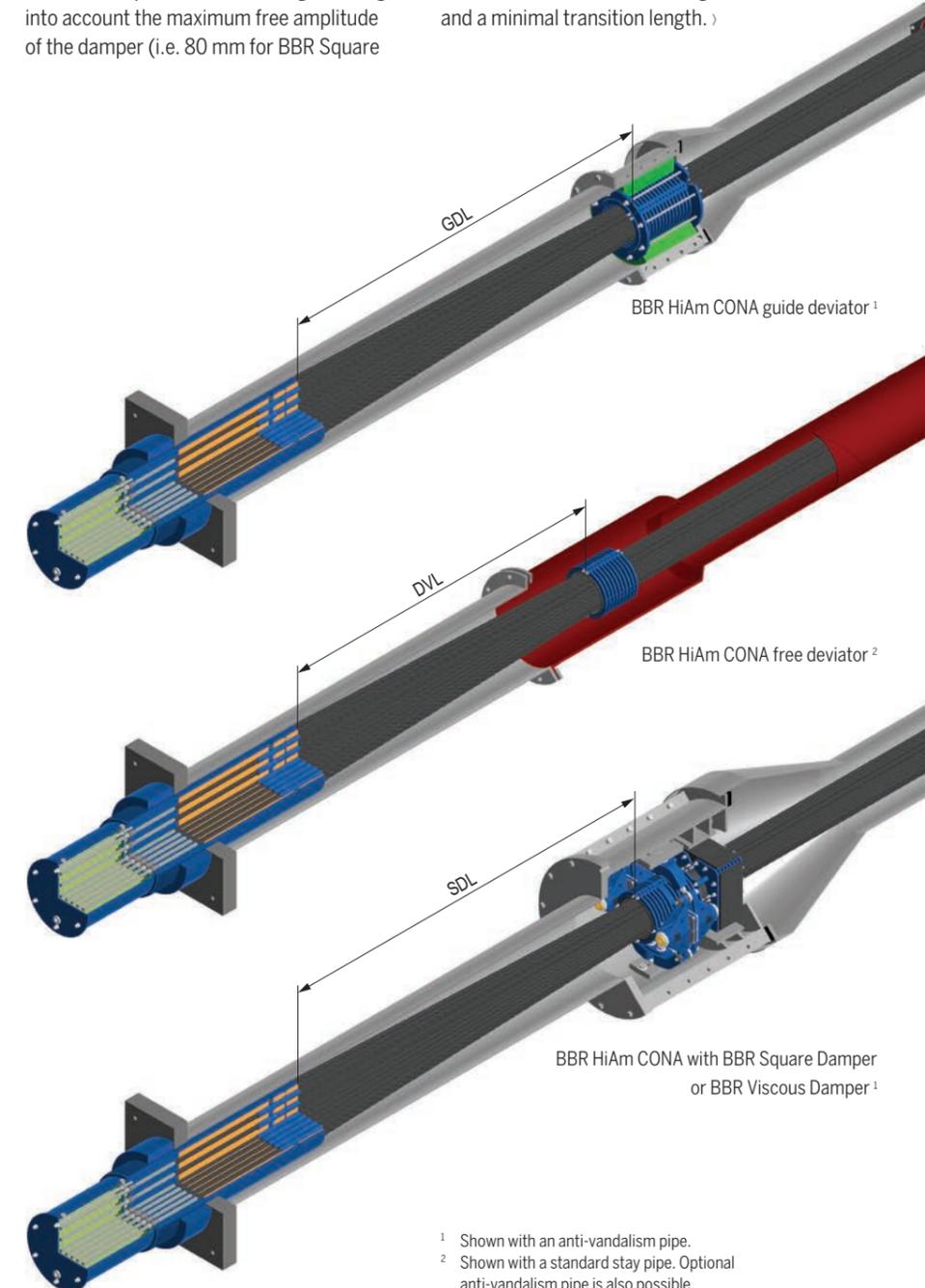
### Free deviator

Use of a guide deviator is not necessary if construction tolerances and anchorage rotations under the governing service and ultimate limit states are moderate and below the applicable limit of national regulations, PTI or fib (e.g.  $\pm 0.3^\circ$  and  $\pm 1.4^\circ$ , respectively). In such cases where a free deviator is used, consideration should be given to installing BBR dampers to avoid any possibly large additional anchorage rotations caused by cable vibrations. When using a free deviator, the minimum required transition length is denoted by DVL with the option of adjustment for different anchorage rotations, see pages 14 and 15.

### BBR dampers

If a BBR damper is installed to add supplemental damping to the stay cable, the transition length must be adjusted so that the transversal movement at the damper location – due to service loads, wind, temperature and cable vibration – can be introduced safely into the anchorage. When a standard BBR damper is used, the minimum required transition length, taking into account the maximum free amplitude of the damper (i.e. 80 mm for BBR Square

Damper), is denoted by SDL, see pages 14 and 15. This distance, however, might be increased due to significant structural rotations at the location of the anchorage or to provide additional supplemental damping. For special applications, an additional BBR Bending Damper outside of the socket of the BBR HiAm CONA anchorage can be considered, which allows for higher rotations and a minimal transition length. >



<sup>1</sup> Shown with an anti-vandalism pipe.

<sup>2</sup> Shown with a standard stay pipe. Optional anti-vandalism pipe is also possible.

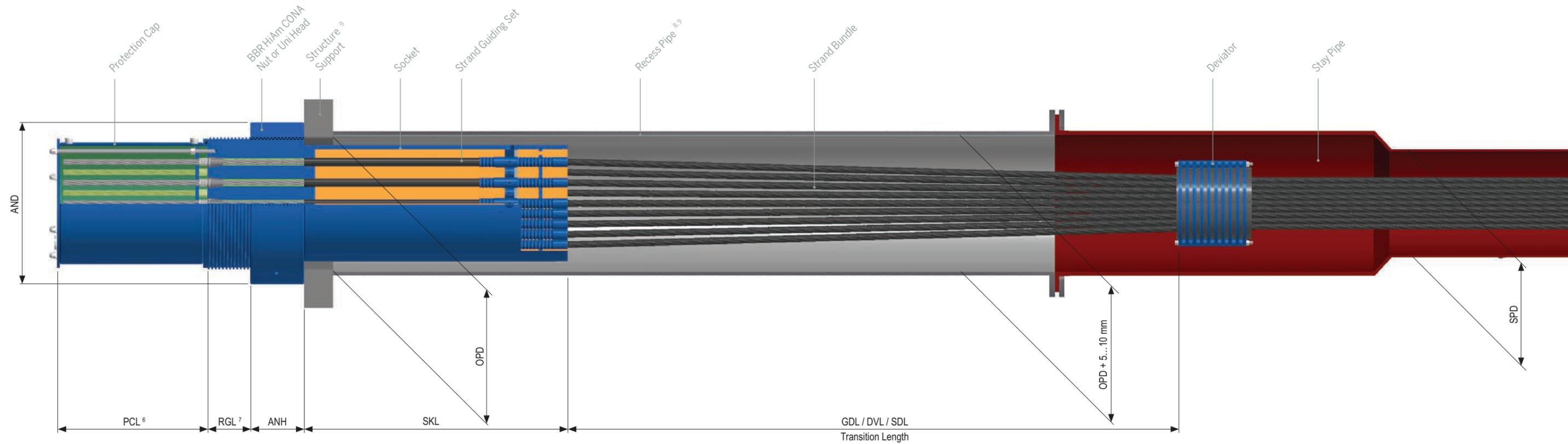


Table 1. BBR HiAm CONA technical specifications

BBR HiAm CONA	Type		001 06	002 06	003 06	004 06	007 06	012 06	013 06	019 06	022 06	024 06	027 06	031 06	037 06	042 06	043 06	048 06	055 06	061 06	069 06	073 06	075 06	085 06	091 06	097 06	109 06	121 06	127 06	151 06	169 06	185 06	217 06
BBR HiAm CONA	Number of strands <sup>1</sup>	n	1	2	3	4	7	12	13	19	22	24	27	31	37	42	43	48	55	61	69	73	75	85	91	97	109	121	127	151	169	185	217
	Breaking Strength <sup>2</sup>	[kN]	279	558	837	1,116	1,953	3,348	3,627	5,301	6,138	6,696	7,533	8,649	10,323	11,718	11,997	13,392	15,345	17,019	19,251	20,367	20,925	23,715	25,389	27,063	30,411	33,759	35,433	42,129	47,151	51,615	60,543
Standard Stay Pipe	Standard Diameter	SPD [mm]	-	50	63	63	90	110	110	125	140	140	160	160	180	180	200	200	200	225	225	250	250	250	280	280	280	315	315	355	400	400	450
	Wall Thickness	SPT [mm]	-	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.6	5.6	6.3	6.3	6.3	7.0	7.0	7.8	7.8	7.8	8.8	8.8	8.8	9.8	9.8	11.1	12.5	12.5	14.1
Compact Stay Pipe	Standard Diameter	SPD [mm]	-	50.0	50.0	63.0	90.0	90.0	110.0	110.0	125.0	125.0	140	140	160	160	160	180	180	200	200	225	225	225	250	250	250	280	280	315	315	355	355
	Wall Thickness	SPT [mm]	-	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.6	5.6	6.3	6.3	7.0	7.0	7.0	7.8	7.8	7.8	8.8	8.8	9.8	9.8	11.1	11.1
Nut Head & Standard Uni Head Anchorage <sup>3</sup>	Height	ANH [mm]	45	55	55	65	65	75	75	90	95	100	105	110	120	125	125	135	140	150	155	160	165	175	185	185	200	215	230	245	250	255	275
	Diameter	AND [mm]	80	115	140	155	180	215	230	265	285	295	310	325	355	375	390	400	425	450	475	490	495	525	545	560	595	625	640	700	755	780	860
	Length	SKL [mm]	485	535	585	685	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735	735
Short Socket Uni Head Anchorage	Height	ANH [mm]	100	100	100	100	105	105	105	110	115	120	125	130	140	145	145	155	160	180	185	190	195	205	215	215	230	245	260	280	295	310	330
	Diameter	AND [mm]	78	115	127	135	166	200	217	249	271	289	293	308	336	356	367	384	391	423	451	457	468	478	518	532	546	588	603	644	725	739	809
	Length	SKL [mm]	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	215	215	215	215	215	215	215	215	215	215	215	215	215
Guide Deviator <sup>4</sup>	Distance from Socket	GDL [mm]	240	240	275	335	475	720	820	945	1,080	1,180	1,190	1,250	1,415	1,515	1,635	1,660	1,705	1,890	1,965	2,060	2,130	2,165	2,360	2,455	2,500	2,630	2,835	2,950	3,305	3,305	3,775
Free Deviator <sup>4</sup>	Distance from Socket	DVL [mm]	-	270	310	380	535	820	930	1,070	1,230	1,340	1,350	1,415	1,605	1,720	1,855	1,880	1,930	2,140	2,230	2,335	2,415	2,455	2,675	2,780	2,830	2,980	3,210	3,340	3,745	3,745	4,280
Damper <sup>4,10</sup>	Distance from Socket	SDL [mm]	1,285	1,465	1,495	1,555	1,685	1,890	1,930	2,085	2,185	2,185	2,290	2,320	2,485	2,540	2,600	2,690	2,715	2,885	2,935	2,985	3,090	3,115	3,285	3,285	3,375	3,510	3,685	3,765	4,090	4,090	4,490
Opening	Standard	OPD [mm]	68	98	121	133	148	183	198	228	245	248	258	268	296	309	325	330	352	370	392	403	408	433	448	461	488	513	525	573	623	638	713
	Short Socket	OPD [mm]	63	97	103	109	129	168	180	200	219	232	235	245	270	283	295	308	308	334	360	360	372	372	412	424	424	464	476	489	568	568	632
	Compact <sup>5</sup>	OPD [mm]	63	91	102	110	130	165	178	198	218	231	233	242	268	282	299	302	310	336	347	360	370	375	402	415	422	441	470	486	536	536	603
Weight	Stay Cable	m <sub>s</sub> [kg/m]	1.3	3.4	4.7	6.0	10.3	17.1	18.4	26.4	30.7	33.3	37.8	43.1	51.6	58.2	60.2	66.8	75.9	84.8	95.3	101.7	104.3	118.9	126.8	134.7	152.4	168.1	176.0	210.0	236.9	257.8	303.9

BBR reserves the right to change the system specifications without prior notice

<sup>1</sup> Intermediate anchorage sizes can be obtained by omitting strands in standard anchorage types.

<sup>2</sup> Given breaking strength is for pre-stressing strand with a nominal diameter of 0.62", nominal cross-section of 150 mm<sup>2</sup> and a guaranteed ultimate tensile strength of 1,860 MPa. Prestressing strands with lower nominal values may also be used. For higher strength strands please contact your nearest BBR representative.

<sup>3</sup> Outside dimensions (AND) and (ANH) are identical for the BBR HiAm CONA Nut Head (adjustable / stressing end) and the BBR HiAm CONA Uni Head (non-adjustable / dead-end), see page 12.

<sup>4</sup> For details on Transition Lengths see page 13.

<sup>5</sup> For information on Compact anchorages see page 12.

<sup>6</sup> Length of the protection cap (PCL) varies depending on the stressing and de-stressing requirements. Reference values are 60 mm for the dead end and 420 mm for the stressing end of the stay cable.

<sup>7</sup> Regulation length (RGL) of the anchorage can be adjusted to any requested value. Reference values are 0 mm, 60 mm or 120 mm.

<sup>8</sup> In case of concrete embedded steel tubes, the suggested wall thickness is 2% ... 2.5% of the outside diameter of the recess pipe.

<sup>9</sup> Integral parts of the structure.

<sup>10</sup> The BBR Viscous Damper is project dependent. Both internal and external viscous dampers require their own damping analyses.

# BBR Pin Connector



The BBR HiAm CONA Pin Connector is the perfect blend of strength and beauty, while at the same time it extends the inherent benefits of the BBR HiAm CONA family. The BBR HiAm CONA Pin Connector is a beneficial solution for stay cable structures where it is necessary to simplify the end connection detail or to have a certain rotational capability along a specific axis.

### Key Benefits

- Aesthetical design
- Superior fatigue resistance
- Minimized bending effects
- Improved construction tolerances and reduced misalignments
- Flexibility during installation
- No internal access to the pylon needed

The pin connector anchorage integrates two ear-like anchoring plates to a main cylindrical body where the standard HiAm CONA Nut Head is threaded in. Each anchoring plate contains a hole through which the pin element is installed and the load is transferred from the stay cable to the superstructure through the clevis plate.

### Design and testing

The BBR Pin Connector has been designed according to European Standards against Ultimate Load State (ULS) and Fatigue Load State (FLS). Design regulations given in the European Standards have been strengthened to contemplate bending actions such as those originating from oscillations of the stay cable in the horizontal direction. The actual ultimate axial capacity and axial fatigue performance of the BBR Pin Connector have been verified under ultimate and axial fatigue with subsequent load testing according to *fib* and according to the more stringent BBR benchmark requirements.

### Transition length

Similar to standard HiAm CONA Stay cables, stay cables terminating with a BBR Pin Connector have their strand bundle at the free deviator and within a transition length spread out towards the socket. At the opposite end to a BBR Pin Connector, all options (free deviator, guide deviator and BBR dampers) are possible and the most suitable option should be chosen at an early stage to fit with the project requirements. Transition lengths for all options can be found on pages 14 and 15 and are listed for each particular size.

### Main advantages

- As well as aesthetical benefits, the BBR Pin Connector provides several important technical advantages:
- The connection detail of the anchorage to the pylon is simplified. Such that the dimensions of the pylon might be reduced.
  - Bending effects due to service loads and wind actions that induce cable oscillations in the vertical direction are mostly mitigated through the rotational capability of the BBR Pin Connector.
  - Similarly, construction tolerances leading to vertical misalignments are also absorbed by the free rotational capability.
  - Stay cable installation might be performed by initial preassembly on site and posterior lifting or according to a strand-by-strand process depending on the project requirements.
  - The BBR Pin Connector with optional window on medium-to-large sizes allows for in-situ wedge inspection and strand replacement.
  - The same sealing detail used in the BBR HiAm CONA family, which successfully passed leak tightness testing, is incorporated in the BBR Pin Connector.

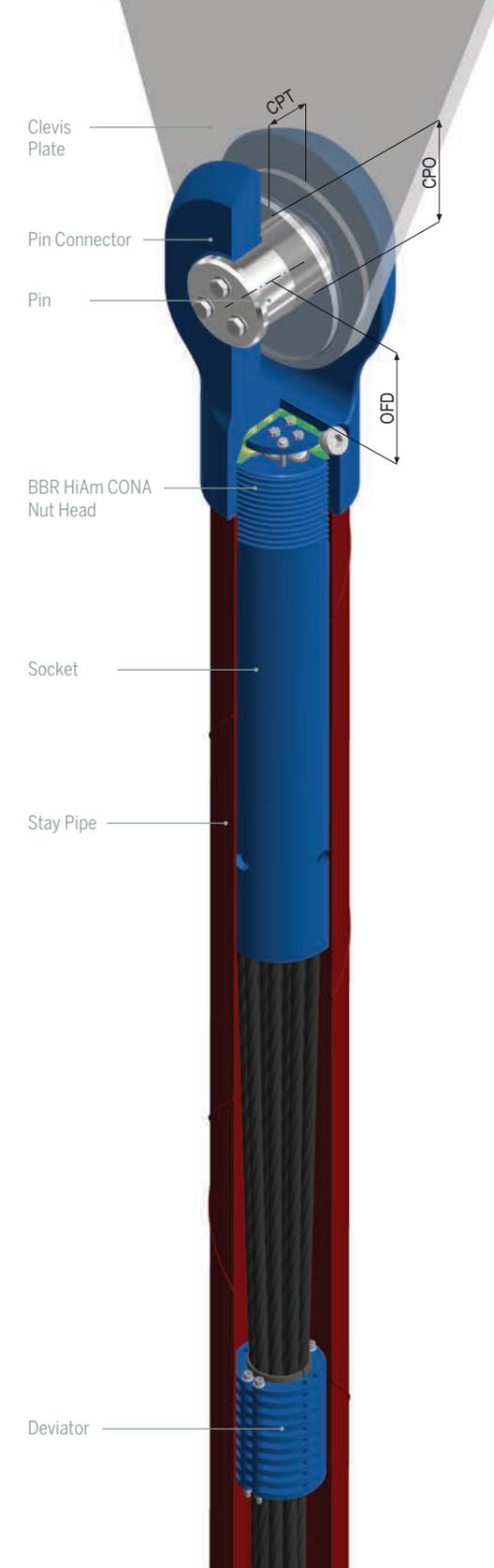


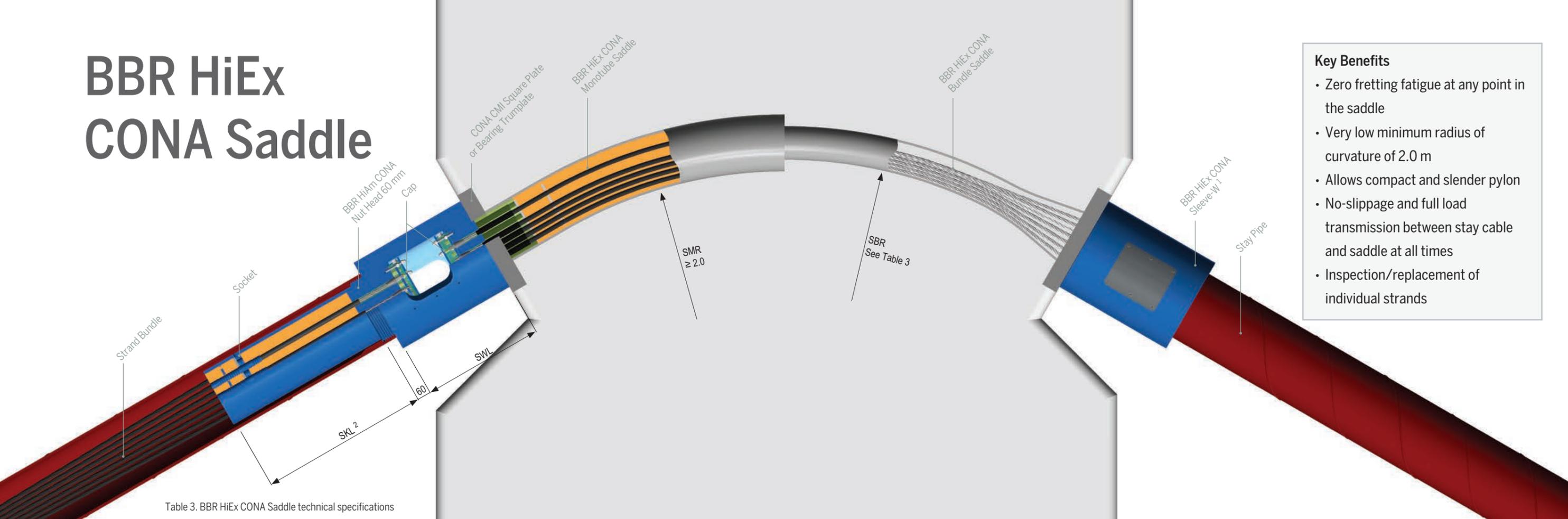
Table 2. BBR HiAm CONA Pin Connector technical specifications

BBR HiAm CONA	Type		002 06	003 06	004 06	007 06	012 06	013 06	019 06	022 06	024 06	027 06	031 06	037 06	042 06	043 06	048 06	055 06	061 06	069 06	073 06
Pin Connector	Number of strands	n	2	3	4	7	12	13	19	22	24	27	31	37	42	43	48	55	61	69	73
	Breaking Strength	[kN]	558	837	1,116	1,953	3,348	3,627	5,301	6,138	6,696	7,533	8,649	10,323	11,718	11,997	13,392	15,345	17,019	19,251	20,367
Anchorage <sup>1</sup>	Opening Diameter	CPO [mm]	55	66	74	94	121	124	148	157	165	173	185	200	212	215	226	241	253	268	275
	Thickness	CPT [mm]	30	37	43	57	74	77	93	100	104	111	118	129	138	139	147	158	166	176	182
	Front Distance	OFD [mm]	112	131	147	186	238	244	291	308	340	340	362	392	415	421	442	472	495	524	538

BBR reserves the right to change the system specifications without prior notice

<sup>1</sup> Dimensions for clevis plate made of steel grade S355. For different steel grade please contact your nearest BBR representative.

# BBR HiEx CONA Saddle



- Key Benefits**
- Zero fretting fatigue at any point in the saddle
  - Very low minimum radius of curvature of 2.0 m
  - Allows compact and slender pylon
  - No-slippage and full load transmission between stay cable and saddle at all times
  - Inspection/replacement of individual strands

Table 3. BBR HiEx CONA Saddle technical specifications

BBR HiEx CONA	Type		012 06	013 06	019 06	022 06	024 06	027 06	031 06	037 06	042 06	043 06	048 06	055 06	061 06	069 06	073 06	075 06	085 06	091 06	097 06	109 06	121 06	127 06	151 06	169 06	185 06	217 06
	Number of Strands	n	12	13	19	22	24	27	31	37	42	43	48	55	61	69	73	75	85	91	97	109	121	127	151	169	185	217
	Breaking Strength	[ kN ]	3,348	3,627	5,301	6,138	6,696	7,533	8,649	10,323	11,718	11,997	13,392	15,345	17,019	19,251	20,367	20,925	23,715	25,389	27,063	30,411	33,759	35,433	42,129	47,151	51,615	60,543
Sleeve	Sleeve-W Length	SWL [ mm ]	440	440	470	480	485	495	510	530	540	540	555	575	585	605	615	625	645	665	675	695	725	755	795	825	855	895
Bundle BBR Saddle	Minimum Radius Bundle, f = 0.25	SBR [ m ]	2.3	2.4	2.9	3.2	3.3	3.5	3.8	4.1	4.4	4.4	4.7	5.0	5.3	5.6	5.7	5.8	6.1	6.3	6.5	6.9	7.2	7.4	8.0	8.5	8.9	9.5
	Minimum Radius Bundle, f = 0.35	SBR [ m ]	2.8	2.9	3.5	3.8	3.9	4.2	4.4	4.9	5.2	5.2	5.5	5.9	6.2	6.6	6.8	6.8	7.2	7.5	7.7	8.1	8.6	8.7	9.5	10.0	10.5	11.3

<sup>1</sup> International Registered Design  
<sup>2</sup> Socket length can be found on pages 14 and 15 for each particular size.

BBR reserves the right to change the system specifications without prior notice

The BBR HiEx CONA Saddle completely eliminates the problems associated with standard friction saddles and, at the same time, allows for a compact and slender pylon. The BBR HiEx CONA Saddle represents the newest and most modern saddle for stayed and extradosed bridges.

The connection of stay cables to the pylon can be made through standard anchorages or saddles. Historically, the connection to the pylon has been mostly made using stay cable anchorages, although over time some designers have elected to replace the standard anchorages by friction saddles or saddles equipped with shear keys with the intention of reducing the pylon's dimensions.

However, friction saddles exhibit some significant drawbacks which discourage their use – for example, inspection/replacement of load carrying elements is impossible and they can suffer from fretting fatigue, as well as slippage when faced with moderate differential forces, or during strand installation and removal/replacement.

### Ahead of friction saddles

The technical solution results from the combination of the following approved and tested systems:

- The BBR VT CONA CMI internal post-tensioning multi-strand system.
- The BBR HiAm CONA Strand Stay Cable System.

The installation of a CONA CMI post-tensioning tendon, as a substitute to the standard friction saddle, creates a compressive concrete environment and provides a fixing point for the stay cable at the pylon. The connection of both CONA CMI and BBR HiAm CONA is realized with the BBR HiEx CONA Sleeve-W which incorporates two windows to allow wedge inspection, strand-by-strand installation and cable replacement.

### BBR HiEx CONA configurations

The standard BBR HiEx CONA Saddle configuration consists of a parallel arrangement of individual guiding systems surrounded by a high strength grout – all enclosed in a curved smooth steel pipe – **BBR HiEx CONA Monotube Saddle**. Seven-wire HDPE-sheathed prestressing steel strands – factory provided with corrosion protection filling material – are inserted

through the guiding system and connect the coupler heads placed at both sides of the pylon. While the high strength grout provides a stiff environment, strands are fully replaceable as there is no bonded connection between the guiding system and the external HDPE of the strands. The minimum radius of this saddle configuration, SMR is 2.0 m. Alternatively, a bundle of bare strands bonded/unbonded to the pylon might also be used if permitted at the place of use – **BBR HiEx CONA Bundle Saddle**. The minimum radius of this saddle configuration, SBR, depends on the degree of filling and maximum contact pressure permitted at the place of use. The actual minimum radius for typical degrees of filling and maximum contact pressures can be found above for each particular size.

### BBR HiEx CONA Sleeve-W

The BBR HiEx CONA Sleeve-W has been designed according European Standards based on Ultimate Load State (ULS) and Fatigue Load State (FLS). These fatigue design criteria combine the most restrictive specifications for stayed and extradosed bridges.

### Saddle fatigue testing

The BBR HiEx CONA Saddle has been tested for both ultimate axial load transfer and fatigue with subsequent loading. Fatigue testing was carried out to an axial stress-range of 200 MPa for 2,000,000 load cycles with anchorage rotations of 0.6° at an upper axial load of 55% GUTS, which covered both *fib* and CIP(Setra) specifications for stay cable and extradosed applications. Fatigue testing has been carried out on the BBR HiEx CONA Saddle to stress range, axial upper load and acceptance criteria which exceeded recommendations from *fib*, CIP(Setra) and EAD 16.

### Precluding differential forces

The action of the live loads on two subsequent spans might lead to differential forces on both sides of the saddle. Those differential forces should not lead to any slippage of the cable with respect to the saddle. Contrarily to friction saddles – that try to compensate differential forces with the friction between the strand and the inner material of the saddle – the BBR HiEx CONA Saddle is a fixed structural point which ensures no-slippage and full load transmission between the stay cable and the saddle even under load scenarios that exceed the maximum permissible loads (i.e. 60% GUTS for accidental or short-term, according to *fib*). The BBR HiEx CONA Saddle is proven by testing to transfer more than 95% GUTS. >

# BBR Damping Systems

## Transition length

Stay cables equipped with a BBR HiEx CONA Saddle have their strand bundle at the deviator and within a transition length spread out towards the socket. On the saddle side, free and guide deviators are possible. On the deck side, all options (free deviator, guide deviator and BBR dampers) are possible and the most suitable option should be chosen at an early stage depending on the project requirements. Transition lengths for all options can be found on pages 14 and 15 for each particular size.

## Main advantages

The BBR HiEx CONA Saddle preserves the key benefit of the saddle concept – that is, reduction of the space required at the pylon – while exhibiting unquestionable benefits with respect to friction saddles:

- The stay cable technology, BBR HiAm CONA anchorages, used on left and right stay cables is proven and tested according to *fib* and other recommendations.
- The saddle is equipped with tested and approved BBR VT CONA CMI post-tensioning technology.
- The BBR HiEx CONA Sleeve-W ensures that the entire differential force appearing at both sides of the pylon is fully absorbed without slippage at the saddle.
- Axial fatigue and fretting fatigue on the saddle are eliminated. Additionally, the compressive environment prevents the appearance of tension cracks and enhances the corrosion protection.
- Corrosion protection on the BBR HiEx CONA Saddle is greater than in conventional saddles with up to five corrosion barriers in the standard configuration (concrete, duct, grout, sheathing and wax/grease in the strand).
- The BBR HiEx CONA Saddle allows for full inspection of the load carrying elements, strand-by-strand cable installation and cable replacement.
- During installation/maintenance/replacement operations, the BBR HiEx CONA Saddle only requires the replacement of the affected stay at one side of the pylon and not the full length. Replacement is even easier because tensile elements which need to be removed do not cross the pylon.

Figure 1. Maximum transferred force at the saddle

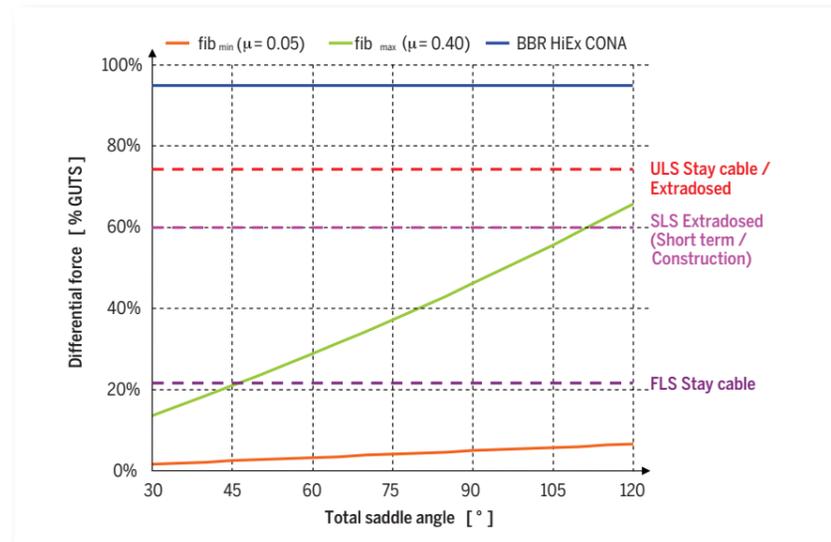
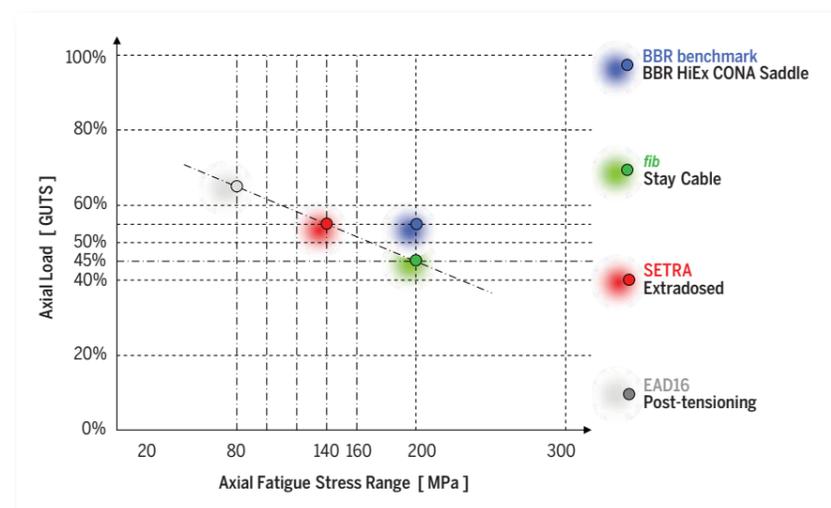


Figure 2. Comparison of different fatigue testing conditions



BBR Damping Systems help to manage excessive vibration caused by live loads and wind effects using the most advanced design and materials allowing easy inspection and extremely low maintenance. BBR offers the most efficient solutions for both friction and viscous dampers.

## Key Benefits

- Simplified maintenance operations
- Viscous and friction solutions
- Superior surface corrosion protection
- Ready for ultra long cables
- Free longitudinal and rotational movement

## BBR Viscous Damper

The BBR Viscous Damper, specially developed to counteract vibrations on stay cables, works based on the resistance induced by the rapid passage of a viscous fluid through a narrow opening. The resistance can dissipate a large amount of energy leading to the damping of the cable. This principle of energy dissipation allows an independent and real-time reaction of the damping device to the occurring vibrations.

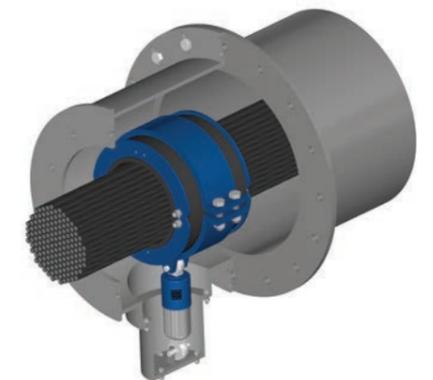
The BBR Viscous Damper consist of twin hydraulic telescopic cylinders. The inner cylinder has the piston working chambers and the outer cylinder works as a housing and reservoir. The BBR Viscous Damper can be installed in either an internal or external damper configuration.

## External viscous damper

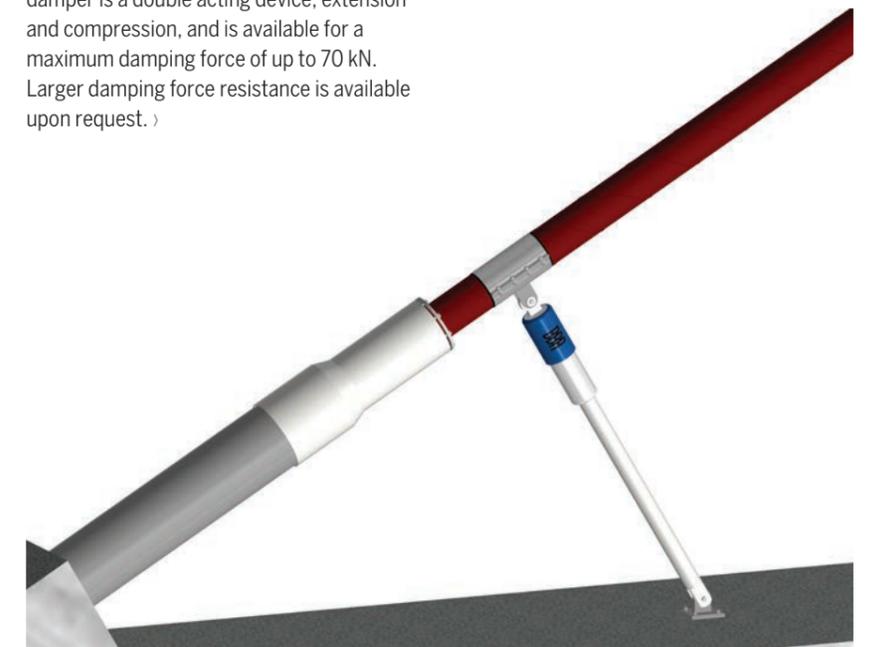
The external viscous damper connects the stay cable directly to the deck without a damper housing. The BBR Viscous Damper (external) is equipped with a superior surface protection coating which protects it from the environment. The standard external damper is a double acting device, extension and compression, and is available for a maximum damping force of up to 70 kN. Larger damping force resistance is available upon request.

## Internal viscous damper

The internal viscous damper is mounted inside a steel housing which gives support and protects against the environment. This compact solution is often preferred because it has a more pleasing design from an aesthetical point of view. The standard BBR Viscous Damper (internal) is a double acting device and available for a maximum damping force of up to 50 kN. Larger damping force resistance is available upon request.



Internal viscous damper



External viscous damper

Note: To reduce supplemental damping, please refer to 'inherent damping' and 'Enhancing cable vibration behavior' section, on pages 27 and 28 respectively.

## BBR Square Damper

The BBR Square Damper is a superior supplemental passive damping device, which is based on friction. The device can be used as an internal damper, where it is installed inside the steel guide pipe or alternatively as an external damper, attached to the cable free length using a damper housing and external brace. If the transversal force on the cable at the damper location exceeds the static friction force of the damper, the damper begins to move with the cable and dissipates energy leading to the damping of the cable.

The basic characteristics of the BBR Square Damper are:

- The damper is not activated at low and non-critical cable vibration amplitudes, avoiding constant working of the damper and minimizing maintenance requirements.
- The damping efficiency is independent of the acceleration and mode of cable vibration.
- The damper has been proven, by testing, to achieve the Maximum Passive Supplemental Damping considered for a 'perfect damper' and thus the safety factors relating to Required Supplemental Damping can be reduced.
- Free longitudinal movement and free rotation of the stay cable at the damper location is provided, allowing for temperature elongation and force variations of the stay cable without constraints.
- The damper can easily be fine tuned at any time.
- The friction parts ensure uniform friction properties and extremely low maintenance.
- Due to its simple design, high efficiency, easy adjustability and low maintenance requirements, the BBR Square Damper is superior compared to other damping devices.

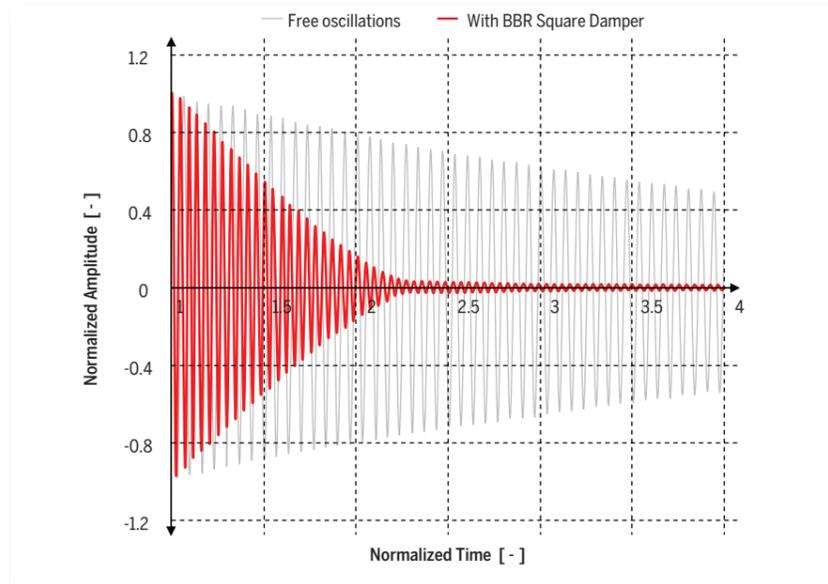


Figure 3. Time-displacement at the middle of the cable

### New generation materials

The development of the BBR Square Damper has included, among others, several multi-million cycles of full damper oscillation wear tests to establish the actual endurance of the friction components. During the tests the temperature was deliberately kept constantly high ( $T > 300\text{ }^{\circ}\text{C}$ ) to promote wear and damage. Such tests proved that only a new generation of friction materials, especially designed for the severity of this applications, can be used.

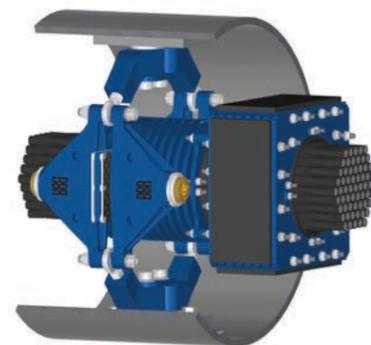
The BBR Square Damper incorporates this new generation of friction materials, together with a ventilation/insulation system to enhance the durability of the components and to extend maintenance intervals.

### R&D on extra long cables

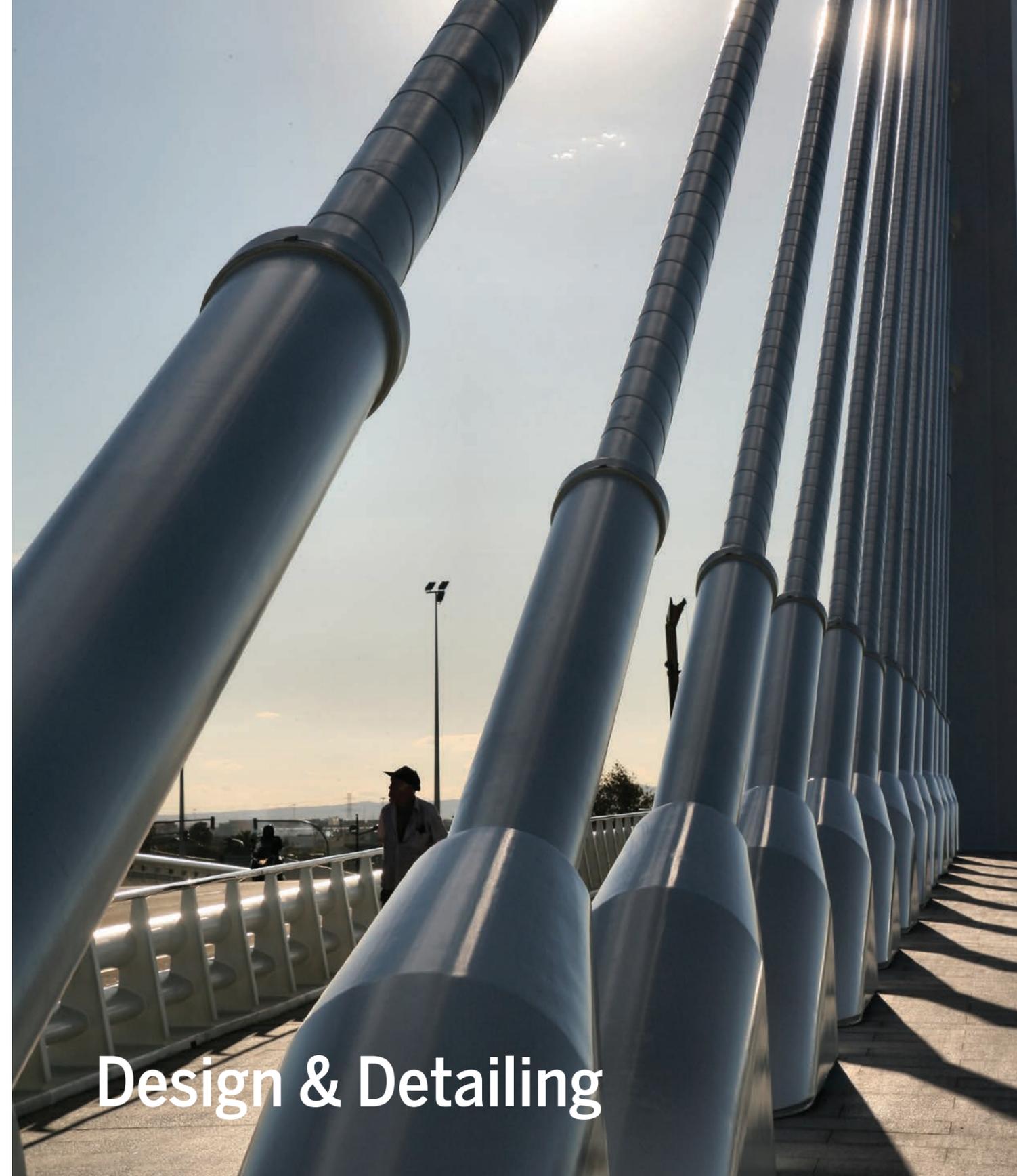
The BBR Square Damper has been extensively tested on multiple cable configurations, including normal and shallow cables. The Maximum Passive Supplemental Damping of each specific configuration for 1<sup>st</sup> to 4<sup>th</sup> mode was always achieved – even in tests on shallow cables with equivalent lengths up to 500 m. •



BBR Square Damper



BBR Square Damper with mechanical stop



## Design & Detailing

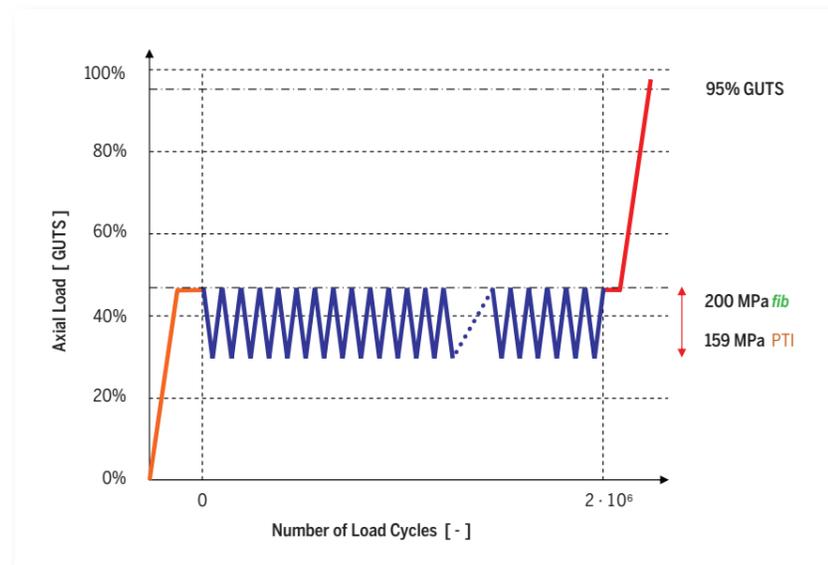
Designers, builders and owners of cable-stayed structures all need to be certain they have specified components which will deliver the level of performance they seek. Consequently, there are a number of classical technical details concerning testing, design and detailing which have to be considered. ›

## Design considerations

### Stay cable anchorage performance testing

The traditional PTI specifies that strand stay cables should withstand certification testing of  $2 \cdot 10^6$  load cycles with a stress range of 159 MPa at an upper load of 45% of the Guaranteed Ultimate Tensile Strength (GUTS) of the tensile elements. The more recent international *fib* recommendations call for a fatigue stress range of 200 MPa. In addition, anchorage rotations of  $0.6^\circ$  are introduced during the test – to simulate construction tolerances. For extradosed type structures, testing provisions may include testing at an upper load of 55% to 60% with a stress range of 120 MPa to 140 MPa. Eventually, the tendon is loaded to failure and the tensile resistance subsequent to the fatigue test must be greater than 95% GUTS.

Figure 4. Fatigue and subsequent tensile test



### Service Limit State (SLS) design

The cross-section of a stay cable is typically sized such that the maximum axial stress in the stay cable under service conditions (SLS) does not exceed the specified limits. In the past, the maximum axial stress was usually limited to 45% GUTS. Due to the more stringent testing requirements, as specified by *fib*, higher axial stresses of up to 50% GUTS are nowadays considered permissible for stay cable applications with high fatigue demands

and in the order of 60% for applications with low fatigue demands (extradosed bridges). Loadings of stay cables during construction or cable replacement should not introduce inelastic deformations in the stay cable system, and a verification of axial stresses against permissible stresses is often sufficient. The permissible axial stresses during construction and cable replacement is typically limited to 60% – 70% GUTS.

### Ultimate Limit State (ULS) design

When verifying the ultimate limit state (ULS), GUTS of the tensile elements can be considered as the characteristic tensile strength of the stay cable system – the resistance factors, in accordance with national standards, should then be applied to find the design strength. If such resistance factors for stay cables are not provided in national codes, one may use a resistance factor of 1.35 for stay cables tested with angular rotation and of 1.50 for stay cables tested without angular rotation.

### Fatigue Limit State (FLS) design

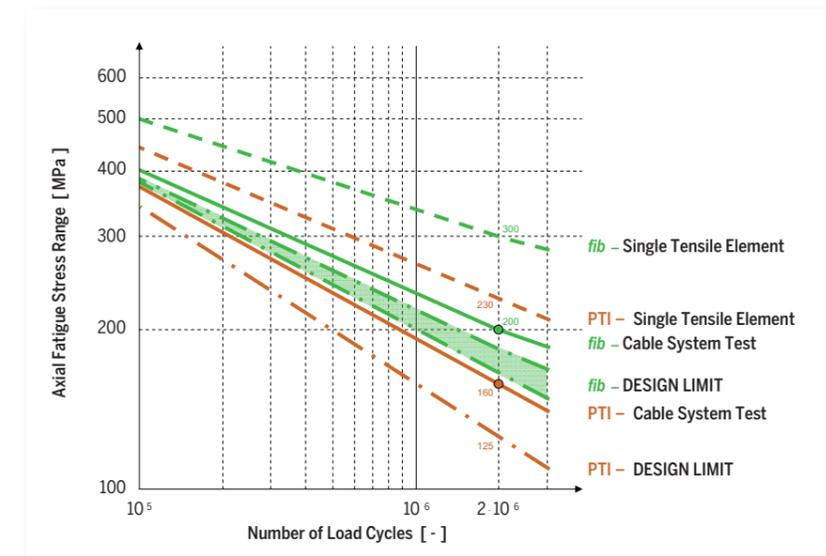
Cable-stayed structures are typically light structures and the stay cables therefore experience high stress variations – so high fatigue resistant stay cables are of great importance. The fatigue design of stay cables has to consider the relevant fatigue loads, in accordance with national standards applied to the particular structure, to determine the fatigue relevant stress range in the stay cables – and then compare it with the fatigue performance of the stay cable system.

In the simplest case, the relevant fatigue load is a specific truck (axle load) and the stress variations in the stay cable created by this loading which are then compared with a reduced stay cable fatigue test resistance, whereas the reduction depends on national regulations.

Figure 5. Typical loads in stay cables



Figure 6. S-N fatigue curves



In an actual design situation, fatigue verification may need to be performed at a number of load cycles – other than  $2 \cdot 10^6$  load cycles, where 'Wöhler-Curves' (S-N curves) can be used.

### Fire and impact

Bridges are well-ventilated and are therefore rarely exposed to high temperatures in the event of a fire. If a truck were to catch fire on a cable-stayed bridge, the resultant blaze would normally be unlikely to affect more than one stay cable at a time – except where stay cables are closely grouped, for example, back stays. Structural stability is thus not generally a problem. However, some bridges are located in special environments – such as near fuel depots or oil refineries – where they will be frequently be used by fuel trucks. In such cases, improved fire resistance of stay cables may be justified to avoid loss of main tensile elements in the event of a fire. Typical fire or impact design considerations establish that the failure of one single stay cable should not lead to failure of the entire cable-stayed structure. The designer should also take into account the dynamic effects caused by the breakage of the stay. Additional measures might be required for grouped stay cables, where structural impact barriers are provided for protection. Alternatively the stay cable may also be fire rated using a special fire protection system. Contact BBR for further details.

### Replaceability of stay cables

Stay cable systems should be replaceable – this is particularly important for bridges. At an early stage, a decision should be taken as to whether the stay cables of the structure are going to be replaceable – either individually, or several at a time. It should also be specified whether replacement is feasible under full, reduced or zero traffic load. Typically for highway bridges, individual stay cable replacement should be factored into the design – under reduced traffic load, meaning closure of the nearest traffic lane.



### Durability

Modern stay cables have a multiple layer corrosion protection system and have to undergo severe corrosion and leak tightness testing. Today, modern stay cables – which have been fully tested to the latest provisions – have a projected service life of 100 years.

### Construction tolerances

In order to comply with the assumptions of PTI and *fib* for flexural effects near anchorages, the designer should specify an installation tolerance of the bearing plates and steel guide pipes of  $0.3^\circ$  (5 mrad) around the theoretical axis of the stay cable.

### Transversal loads

Stays in cable-supported structures essentially carry tensile loads. However, although minimal in comparison with axial loads, transverse loads from different sources also act on the stay cables.

Main causes of transverse loads are:

- construction tolerances and misalignments
- change of cable sag caused by construction and traffic loads
- rotation of the anchorage points due to loadings on the structure
- wind loads on the cables
- temperature changes. ›

### Countering transversal loads

Centralizers have often been used to protect the stay cable anchorages from the effects of transverse loads. The transverse support provided by the centralizer to the stay cable causes a kink in the geometry of the stay cable. Consequently, the cable exerts a transversal force to the centralizer and the centralizer to the structure. As guidance for preliminary design of the structure supporting the centralizer, an angular kink of 1.4° (25 mrad) is suggested as a reasonable assumption, which leads to a transversal load in the order of 2.5% of the cable force. For the BBR HiAm CONA system, the use of a guide deviator is not required and the so-called BBR free deviator can be used – this simplifies the deck and pylon detailing significantly. If a BBR free deviator is going to be used at the pylon anchorage, consideration should be given to installing a BBR damper at deck level – to avoid any large anchorage rotations due to cable vibration.

### Bending

Stay cables are characterized, in comparison with other structural elements, by possessing a very great slenderness. This characteristic makes them very flexible under distributed normal loading to their axial configuration – and almost precludes the appearance of bending stresses in their free length. However, stay cables might locally suffer bending stresses at anchorages or when passing over a saddle. In both situations, bending stresses might be of the same order of magnitude as the axial stresses and may require specific analysis. The maximum fixed end index bending stress  $\sigma_B$  [MPa] in stay cables at the anchorage location might be evaluated by the following equation:

$$\sigma_B = 2 \cdot \alpha \cdot \sqrt{E_p \cdot \sigma_A}$$

Where  $\alpha$  [rad] is the angular deviation of the stay cable with respect to the permanent position and  $E_p$  [MPa] and  $\sigma_A$  [MPa] are the Young Modulus and the axial stress in the steel respectively. Evaluating this equation shows that for relatively small deviation angles, the overall stress level (axial stress + bending stress) might exceed the allowable limit. Consequently, it is always recommended that suitable and fully tested provisions are made to minimize the bending stresses occurring at the anchorages.

On the BBR HiAm CONA system, each strand is individually and independently supported with a hyper-elastic guide tube (SmaCu Guide). The SmaCu Guide is designed to support each strand for all applicable design deviation angles over its entire length and this minimizes the curvature imposed on each strand. The SmaCu Guide ensures that the curvature within each individual strand is minimal for the applicable deviation angle and also non-constant. Independently of the applicable deviation angle, the maximum curvature of the strands does not exceed 1/3500, which results in index bending stresses in the strand of only 145 MPa.

### Standard and Compact stay pipe options

In a classic case of circular stay pipes, the value of the drag coefficient depends on the wind velocity, or more specifically on the Reynolds number  $R_e$ , and the roughness of the outer casing.

Three basic ranges of  $C_D$  can be observed:

- Subcritical range at low wind velocity where  $R_e$  is below  $2 \cdot 10^5$ : High drag coefficient of 1.20
- Critical range where  $R_e$  is between  $2 \cdot 10^5$  and  $8 \cdot 10^5$ : The drag coefficient drops significantly
- Supercritical range at high wind velocity where  $R_e$  is above  $8 \cdot 10^5$ : Low drag coefficient of 0.50-0.60.

Wind induces static and dynamic effects on cable-stays and should therefore be taken into account during design. The static drag force of wind on a stay cable causes significant transversal stresses on the pylon, particularly on large cable-stayed bridges. The drag force  $F_d$  [N/m] is given by:

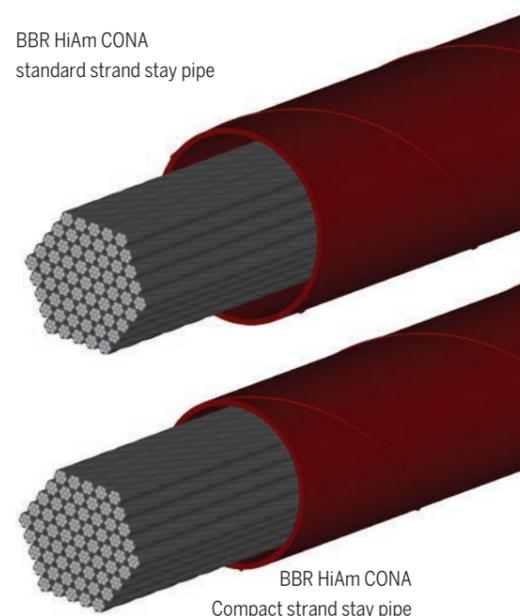
$$F_d = \frac{1}{2} \rho_A \cdot U^2 \cdot D_s \cdot C_D$$

Where  $\rho_A$  [1.25 kg/m<sup>3</sup>] is the density of air,  $U$  [m/s] is the wind velocity,  $D_s$  [m] is the outer cable diameter and  $C_D$  is the drag coefficient. As the formula above indicates, the predominant factor is wind velocity since it is squared. For instance, the drag force increases by 78% when  $U$  rises from 30 m/s to 40 m/s – assuming the other factors remain stable.

Cable stays are commonly in the supercritical range in strong winds. A  $C_D$  of 0.50 for a smooth BBR stay pipe and a drag coefficient of 0.55-0.60 for a BBR stay pipe with helical rib can be achieved in wind tunnel tests. Nevertheless, the effects of extreme winds are often calculated by adopting a  $C_D$  of 0.70-0.80 to be on the safe side and to allow for the possible evolution of surface roughness (dirt build-up, etc) over time.

Reduced wind loads can be achieved by reducing the outer cable diameter. For long span bridges, where the cable stay drag is a preponderant factor, the installation of Compact BBR stay pipes should be evaluated. The Compact system enables the drag force to be reduced by 20% compared to the standard system. This system requires special material and installation techniques on site. BBR's first application of compact stay pipes was in 2000, when the 475 m long Rama VIII Bridge in Bangkok, Thailand was erected.

BBR HiAm CONA standard strand stay pipe



BBR HiAm CONA Compact strand stay pipe

### Cable vibration and damping

Despite the wide use of cable-stayed bridges, there are still several areas of great concern, especially the effects and elimination of cable vibration phenomena.

Even newly constructed cable-stayed bridges have experienced quite severe vibrations. Several cable vibration mechanisms have been identified and characterized, with the four most common phenomena being vortex shedding, galloping, parametric excitation – deck/pylon and cable interaction – and rain-wind induced vibrations. The short-term consequence of cable vibration is complaints from the public – bridge users – the long-term consequences are reduced safety or even failure of complete cables caused by a rapid accumulation of bending fatigue stress cycles at the anchorages.

### Inherent damping

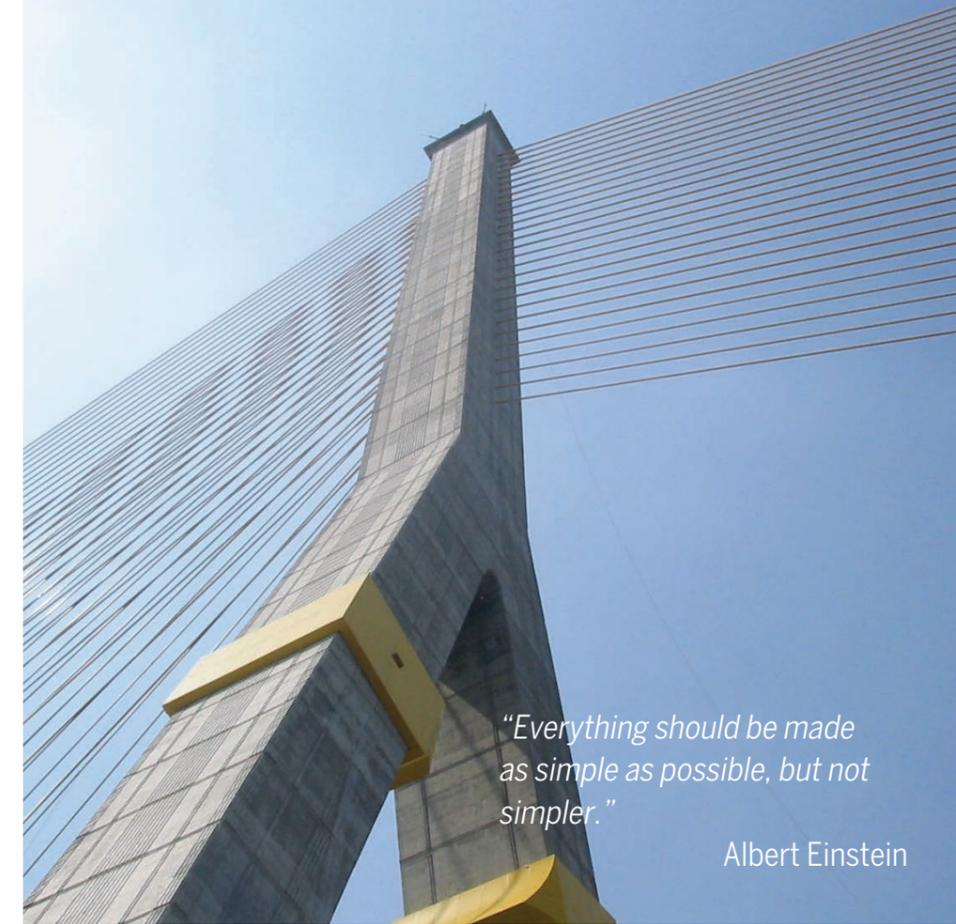
Structural elements have a certain level of inherent "self" damping,  $\delta_i$ , – which, conservatively, for strand stay cables can be assumed as 0.8% logarithmic decrement. The inherent damping of a stay cable is the maximum rate at which the cable dissipates the energy which makes it oscillate. Often the inherent damping is not sufficient to damp the stay cable and then it is necessary to add passive supplemental damping. Additionally to the supplemental damping, the installation of special measures – like surface treatment of the cable and cross-ties – might reduce the Required Supplemental Damping,  $\delta_{Req.Sup}$ , and hence improve the response of the stay cable against vibrations.

### Specification

The Required Supplemental Damping should be specified by the designer for a particular stay cable arrangement, stay pipe configuration (diameter, with or without surface treatment) and stay cable mass. The inherent damping of the particular configuration needs then to be deducted.

A sufficient factor of safety,  $S_F$ , in the order of load factors applied in structural engineering, must be achieved between the Required Supplemental Damping and the Maximum Theoretical Supplemental Damping:

$$\delta_{Req.sup} = 2 \cdot \pi \cdot \frac{S_C \cdot \rho_A \cdot D_s^2}{m_s} - \delta_i \leq S_F \cdot \delta_{Max.Sup}$$



*"Everything should be made as simple as possible, but not simpler."*

Albert Einstein

where  $\delta_{Max.Sup} = \pi \cdot \frac{L_D}{L_S}$

Where,  $S_C$  is the Scruton Number,  $\rho_A$  [1.25 kg/m<sup>3</sup>] is the density of the air,  $D_s$  [m] is the outer diameter of the stay cable,  $m_s$  [kg/m] is the linear mass of the stay cable,  $L_D$  [m] the distance from the anchorage to the damper and  $L_S$  [m] the length of the stay cable.

### Supplemental damping

Along each oscillation a small portion of the energy stored through the stay cable length is lost due to friction phenomena near anchorages. Occasionally the rate at which this energy is lost is very scanty (i.e. low inherent damping) leading to large amplitudes and large number of oscillations. In these scenarios supplemental damping devices increase the energy lost per cycle and reduce the free oscillating time.

The maximum supplementary damping that a perfect damper could provide to a cable (i.e. efficiency of the damper is not considered) solely depends on the relative location of the damper along the cable,  $L_D/L_S$ , and is independent of the nature of the damper (friction, viscous, gas, etc.). In general, dampers are normally installed in medium to long cables ( $L_S \geq 150$  m) at a

distance ~2.5% of the cable length, therefore specific provisions should be made by the designer at an early stage.

Active damping devices are also available, but they require external power sources and high maintenance and should therefore only be considered for repairs and retrofits.

### Damper installation

Dampers are usually installed once stay cables are structurally active and carry the permanent and superimposed loads of the structure. After installation, factors – such as service loads, traffic, wind and temperature – modify the geometry of the entire structure and consequently induce relative rotations between the structure and the stay cable, which result in transversal and longitudinal movements at the damper location. These movements are often larger than those imposed on the damper and on the anchorages by possible cable vibrations. To ensure good damping performance, durability and safety, the damper, stay cables and the anchorages must be seen as an integrated system which has to be analyzed, designed and detailed as a whole. Consequently, both the stay cable and the damping device should be provided by the same company. )

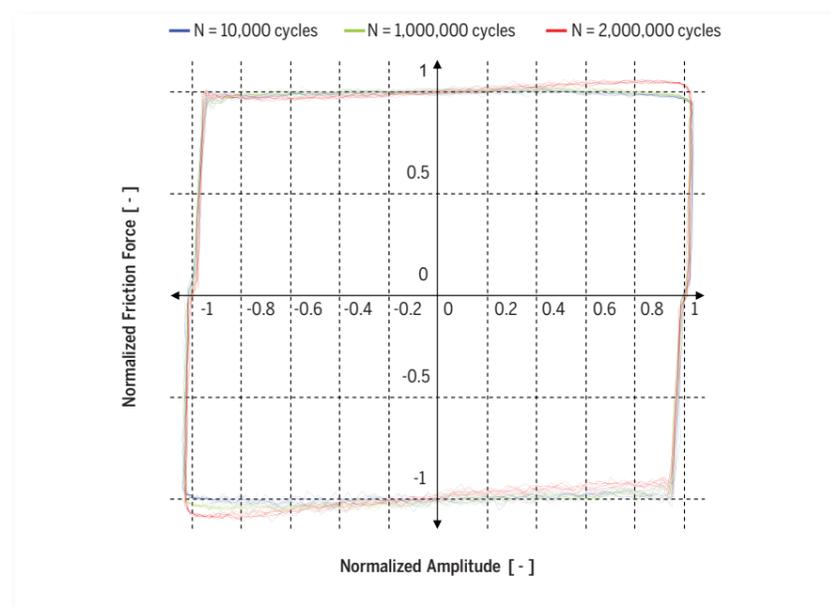
### Countering cable vibration

A preliminary evaluation of the susceptibility of a stay cable to vibration can be performed using the Scruton Number which is a measure of the aerodynamic stability of the cable. In general, it is recommended that the Scruton Number is kept as high as possible and values greater than 10 are often suggested.

Over the years BBR Headquarters has built an extensive knowledge of all these special stay cable phenomena which has led to a wide and comprehensive documentation and to robust and reliable proprietary software tools that allow for a safe, detailed and precise analysis. Among other subjects, BBR provides technical support to stay cable projects on the following:

- An early and precise evaluation of the actual inherent damping for a particular stay cable configuration might avoid the installation of damper devices leading to considerable cost savings.
- Some complex vibration phenomena such as ice-galloping, dry galloping and den Hartog galloping on stay temporary stay cable are not covered by considering standard  $S_c$  values and should be specifically analyzed for each particular project.

Figure 7. Hysteresis behaviour and performance – endurance of the damper



- Long cables oscillating under symmetric vibration modes (i.e. 1<sup>st</sup>, 3<sup>rd</sup>, etc.) are proven to exhibit regions of reduced movement near the anchorages which decreases the actual supplemental damping provided by a damper device. In these scenarios, longer  $L_D$  distances are needed. BBR provides accurate analysis leading to the precise location of the

damper device without over-estimating  $L_D$  that increases costs and harms the bridge aesthetics.

- Dampers must be correctly fine-tuned in order that they provide the best possible performance under the most common vibration modes (i.e. 1<sup>st</sup> and 2<sup>nd</sup> vibration modes).

### Enhancing cable vibration behavior

BBR offers an effective countermeasure against rain-wind induced vibrations by equipping the outside cable surface with a helical rib. The helical fillet helps to prevent the formation of the coherent upper water rivulets, which are responsible for the cable vibrations and therefore mitigates the excitation at its source. Using BBR Strand Stay Pipes with helical rib, the minimum required Scruton Number to prevent rain-wind cable vibration may be reduced to a value as low as 5. Supplemental damping can further be reduced by choosing a Compact BBR Strand Stay Pipe (see page 26). •

## And finally ...



Having reached this page, you can certainly be in no doubt as to our commitment to the finest technology and our enthusiasm for delivering our projects.

Our seven decades of experience has resulted in BBR Technology being applied to over 430 structures and, in the process, we have continued to refine and enhance our range. The result is that we can supply simply the best technology available – the BBR HiAm CONA system.

Technology does not however develop by itself – all through the years, we have been fortunate enough to have attracted some of the best engineers in the business. It is their dedication which has maintained the BBR reputation – and continues to do so today.

Our well-established worldwide network is supported in the development of cable-stayed structures by our Special Projects Team who will help to specify and procure the systems required. So, local knowledge synchronises with international know-how to realise projects – some large, some smaller, but always technically excellent and dramatically beautiful!





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