DYWIDAG-SYSTEMS INTERNATIONAL

DYWIDAG Multistrand Stay Cable Systems

Contents

History

DYWIDAG-Systems International (DSI) is a globally leading system supplier of innovative technologies for the construction industry.

Tradition

The long tradition of DSI reaches back as far as 1865 – the founding year of the German construction firm, Dyckerhoff & Widmann AG (DYWIDAG). DSI was founded in the year 1979 to market DYWIDAG Systems and technical know-how around the world and to develop innovative systems resulting from its own R&D activities.

DSI Technology

In more than 90 countries and at 28 regional manufacturing sites, DSI develops, produces and supplies high quality systems such as DYWIDAG Post-Tensioning Systems, Geotechnical Systems and "Concrete Accessories" for the Construction industry. In accordance with our slogan ***"Local Presence – Global Competence",*** more than 2,100 specialized and experienced DSI employees ensure that DSI's technologies and know-how are available around the world. DSI offers quality on all levels – quality that is characterized by creativity, reliability and profitability.

1928: Saalebridge, Alsleben, Germany
First Bridge with prestressed Beam Tie developed by Dr.-Ing. Franz Dischinger

Comprehensive Services

Our comprehensive services include the conception, design, planning and installation of its systems as well as quality management and on site supervision.

Research & Development

Continued investments in Research & Development and the resulting patent applications sustainably strengthen the know-how available within the DSI Group. By offering innovative solutions in accordance with superior quality standards, we fulfill the constantly changing requirements of our target markets. It is our **declared aim to always be one step ahead.**

Client Orientation

The needs and requirements of clients and business partners are always of paramount importance. Our company is characterized by reliability, trust and cooperation based on partnership. We offer our clients the advantages of an international system supplier with a product range that is tailored to suit individual requirements.

Certifications and International Organizations

International organizations, trade associations and standards committees are becoming more important in times in which products and services seem more and more interchangeable. Organizations and trade associations are cross-linked on a global basis and promote the exchange of technology and know-how across borders. We are an active member in many International Organizations **to drive technical developments.**

Milestones

DYWIDAG Post-Tensioning Systems and Stay Cable Systems are world renowned for reliability and performance; they are perfectly suitable for all applications in post-tensioned construction. They embrace the whole spectrum from bridge construction and buildings to civil applications – both above and below ground.

The first ever structure built with a prototype DYWIDAG Post-Tensioning System using Bars was the arch bridge Alsleben (Germany) in 1927. From that time on, DYWIDAG has continuously improved its systems to keep up with the growing demand of modern construction technology.

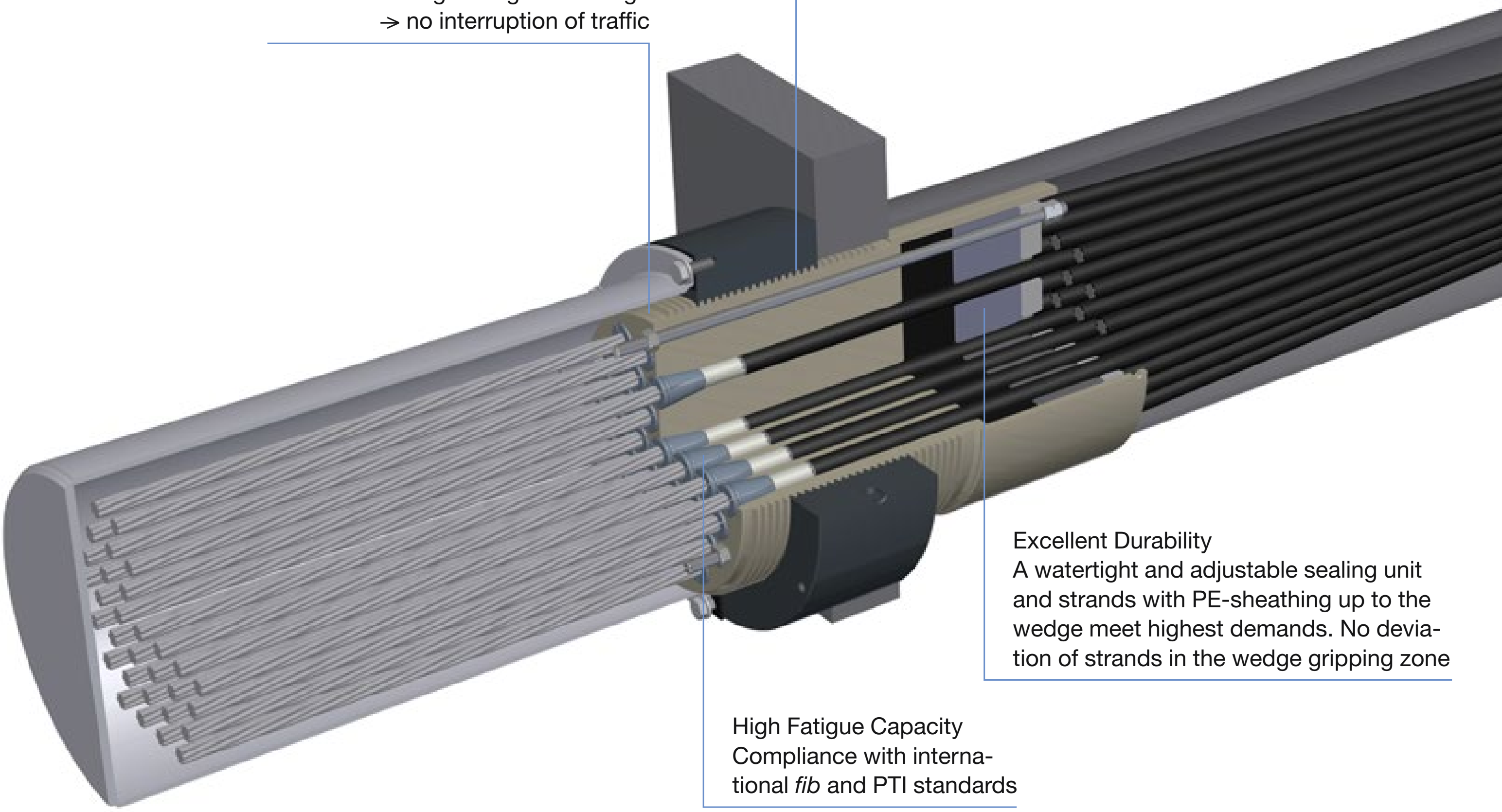
In addition to traditional post-tensioning systems with bars, DSI offers a complete product line in strand post-tensioning (bonded, unbonded and external) as well as stay-cable systems **to fulfill the changing requirements in the industry today and tomorrow.**

Our stay cable systems have always combined the highest safety and reliability standards with excellent economical efficiency in their research and development.

Dependable corrosion protection methods, damper design, fire protection, vibration measurements and the recently developed DYNA® Force monitoring system significantly **contribute to the longevity of modern construction.**

1972: 2. Main Bridge, Hoechst Chemicals, Frankfurt, Germany

1995: Kap Shui Mun Bridge, Hongkong, China
DYNA Bond® Stay Cable Bridge with 176 cables



The DYNA Grip® Stressing Anchorage consists of an anchor block in which the strands are anchored by high fatigue 3 part-wedges. A ring nut is threaded onto the anchor block to transmit the cable force into the structure via the bearing plate. A steel pipe which incorporates bending and sealing provisions for the strands is part of the anchor block. A non-adjustable anchorage with the same provisions for bending and sealing of the strands can be placed at the dead-end side.

High Fatigue Performance

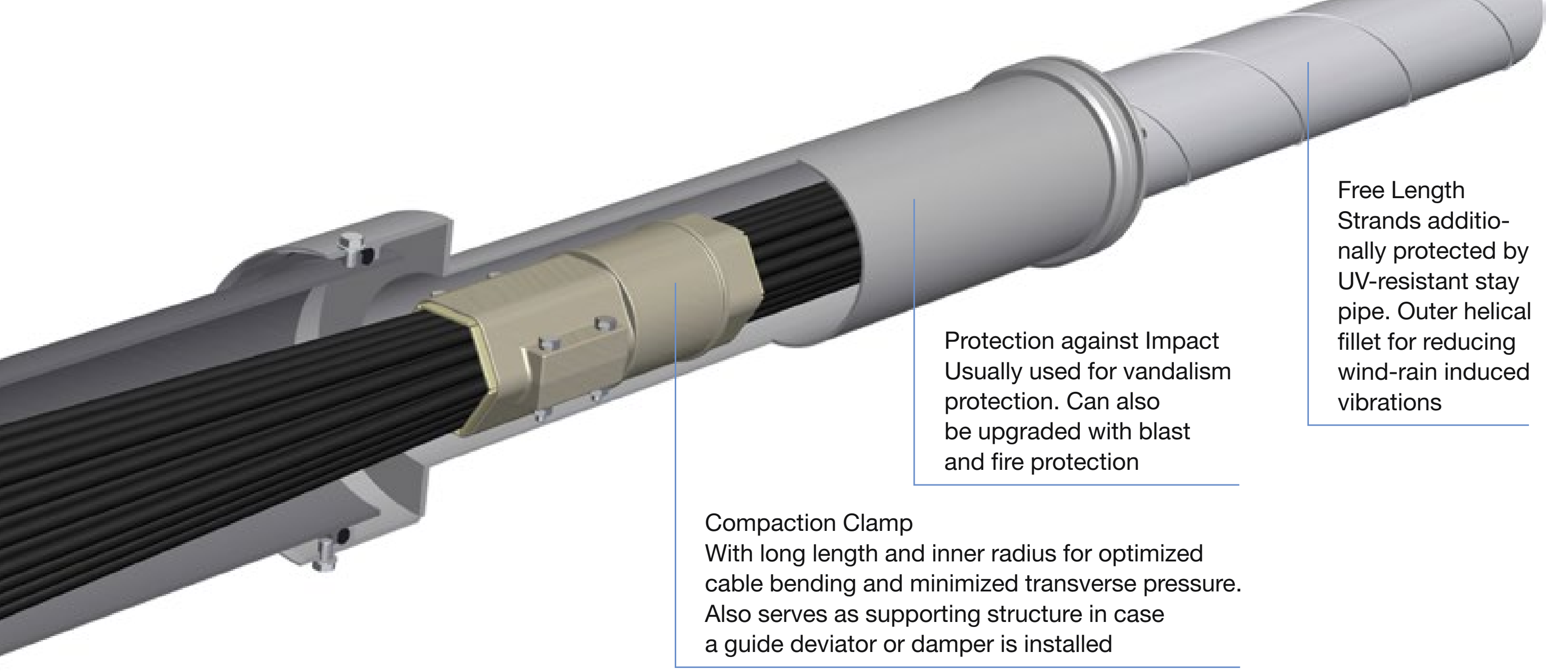
The system has proven its excellent performance and fulfills the requirements of *fib* Bulletin 30 as well as PTI for fatigue and tensile strength:

- Multiple full size tests on cable sizes from 7 to 156 strands
- The system has been successfully tested in standard tests with a stress range of up to 200MPa at an upper stress limit of 45% GUTS and at 2 million load cycles with anchorages inclined by 0.6°. In addition, full size tests have been performed successfully with an upper load of up to 60% GUTS, up to 10 million load cycles and a stress range of up to 250MPa
- Tests on single strands under reversed cyclic flexural loading with 45% and 60% GUTS, 2 million load cycles with anchorages inclined by 3.0° and additional angular deviation between ±10mrad and ±35mrad

The leak tightness of the anchorage area has been demonstrated for the complete system and even meets stringent *fib* and Setra requirements with:

- Up to 3m water head
- Several load cycles in the longitudinal and transverse direction
- Temperature cycling 20–70°C

DYNA Grip® Stay Cable System



Durability and high-quality Corrosion Protection

Strands are guided into the anchorage by an elaborate system that ensures both leak tightness and smooth deviation:

- Compressible sealing plates ensure water and even vacuum tightness
- The correct function can be checked and even adjusted during inspection
- Bending stresses are minimized by a filter that arranges a straight-line entering into the wedge gripping area
- A cap including filler material for the protection of individual strands is placed in front
- Corrosion protection resists corrosivity class C5 in accordance with ISO 12944

The anchorages have been designed for threading the strands including their PE-sheathing through the anchorage:

- Dismantling of the strand's PE-sheathing is minimized to what is absolutely necessary
- The factory applied corrosion protection of the strands continues directly up to the wedges
- Significant reduction of the length of anchorage area where interstices are filled with corrosion protection compound. Both high durability and cost savings in terms of additional filling material are guaranteed.

Free length:

- The strands are protected by a multi-layer system of galvanized wires and are tightly sheathed by HDPE. A wax filling is used for the interstices in between
- An outer stay pipe made of UV-resistant HDPE additionally protects the strands and minimizes rain-wind induced vibrations with an outer helical fillet that provides a low drag coefficient

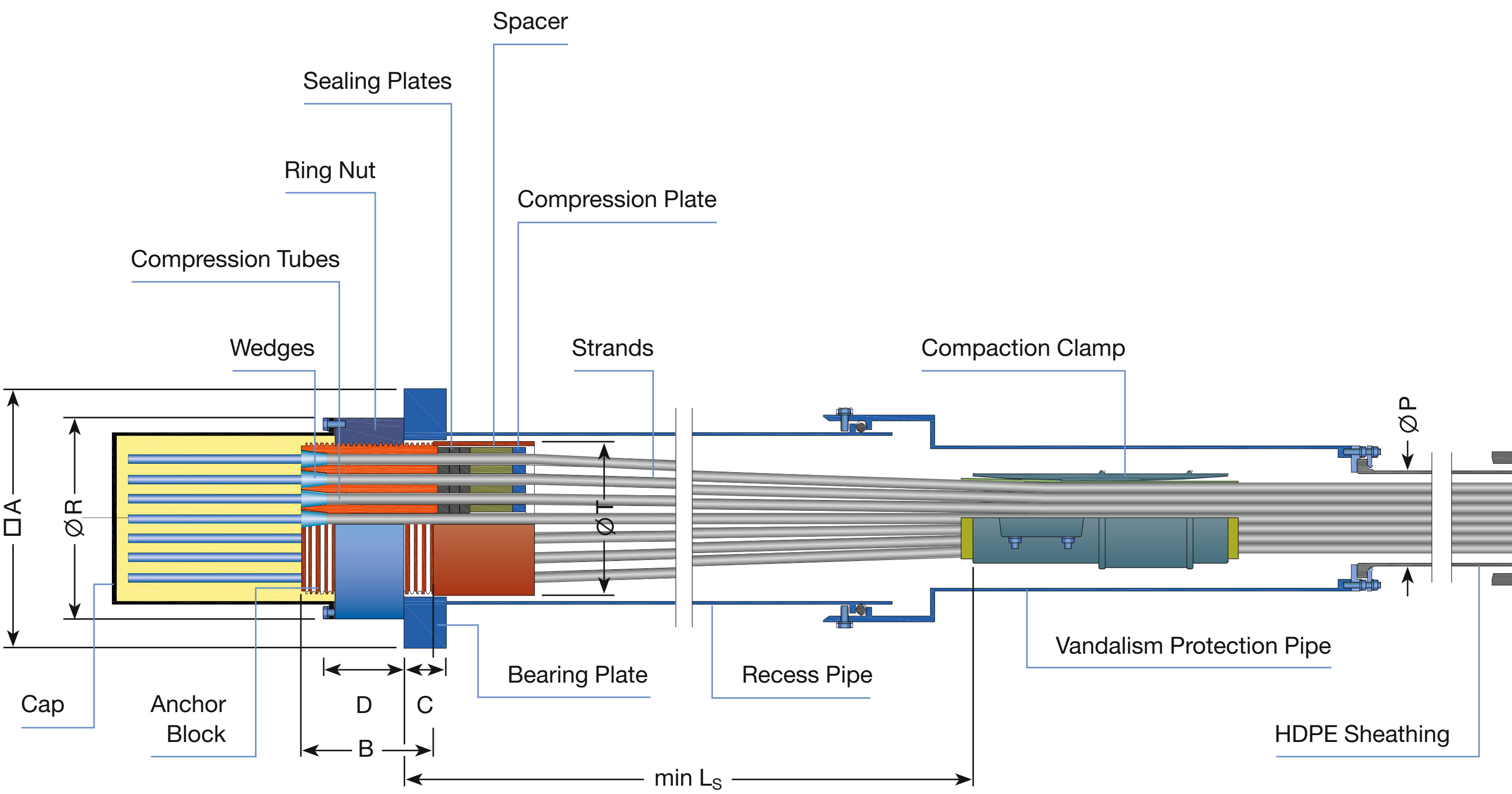
Replaceability of Strands

As the PE-coating is pulled directly through the anchorage, an exchange of strands is possible at any time during the service life of the bridge without the need for renewing or replacing any other cable components.

- Strand exchange is performed directly at the anchorages
- There is no need to remove the cable's outer stay pipe – no disruptions to traffic.

Fast Construction Cycles

- Lightweight equipment for strand installation and stressing operations is provided by DSI
- The use of tower cranes or other lifting equipment can be limited to a minimum
- Non-protruding recess pipes at the pylon → no additional formwork adjustment is required
- No exact dismantling of the strand's outer sheathing is necessary. In case of stressing actions that are additionally required, the strand sheathing is compressed by small tubes in front of the wedges while the strand is pulled through and elongated by the jack.
- A compaction clamp, installed after stressing on the strand bundle, keeps the strand in a compact hexagonal pattern.



DYNA Grip® Anchorage – Technical Data

(forces calculated with strands 0.62" St 1620/1860)

Cable type*		DG-P4	DG-P7	DG-P12	DG-P19	DG-P31
No. of strands		4	7	12	19	31
Forces [kN] **						
Ultimate load at 100% GUTS		1,116	1,953	3,348	5,301	8,649
Service load at 50% GUTS for stay cables		558	977	1,674	2,651	4,325
Service load at 60% GUTS for extradosed tendons		670	1,172	2,009	3,181	5,189
Dimensions [mm]						
Bearing plate ***	☐A	190	250	300	370	460
Bearing plate ***	C	20	25	30	35	40
Bearing plate opening	ØT	112	145	183	219	267
Thread ****	B	140	160	200	220	230
Ring nut	D	50	50	90	110	130
Ring nut	ØR	150	210	244	287	350
Dead anchor	E	50	90	120	120	135
Dead anchor	ØF	150	190	215	261	324
Distance of compaction clamp, stressing end	min L_S	520	650	880	1,080	1,350
Distance of compaction clamp, dead end	min L_D	400	510	740	940	1,210
HDPE sheathing	ØP	63	90	110	125	160

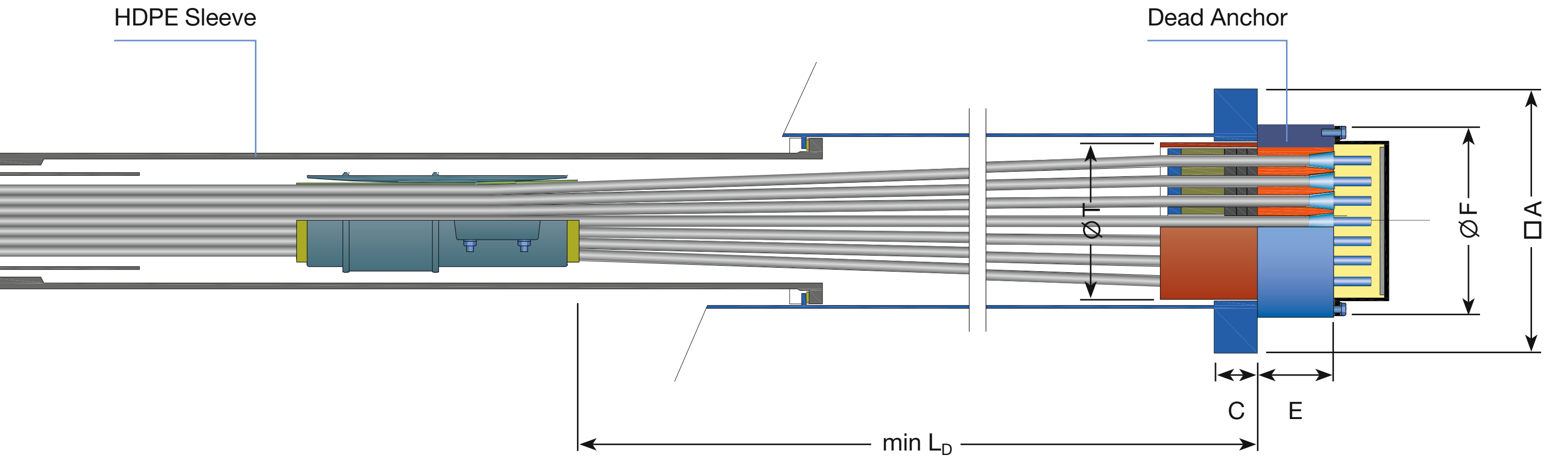
* larger sizes on special request

** local design guidelines must be taken into account

*** dimensions correspond to concrete strength ≥ 35MPa (cylinder) at 45% GUTS according to PTI anchorage zone design

**** standard length, changeable on special request

Subject to modification

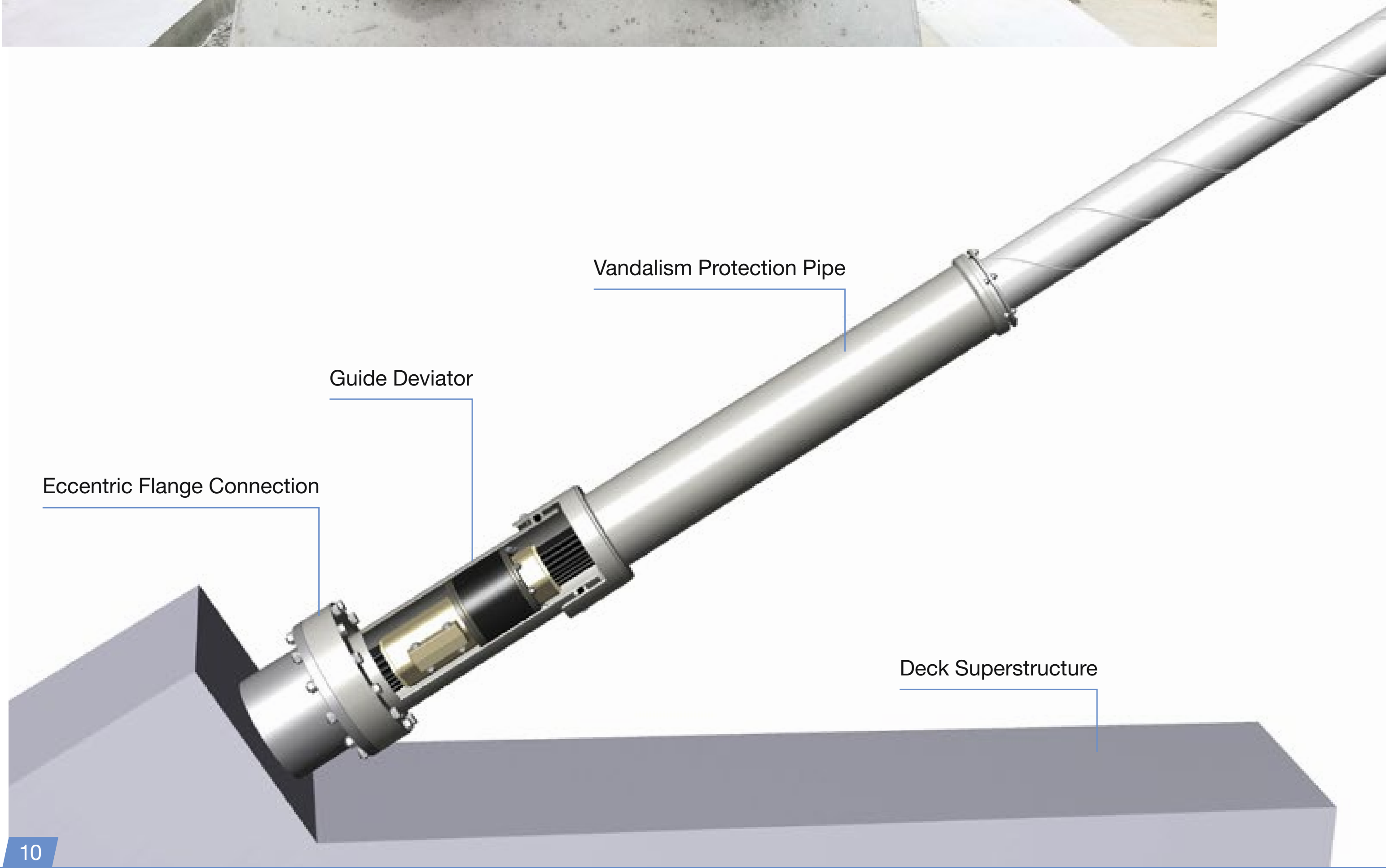


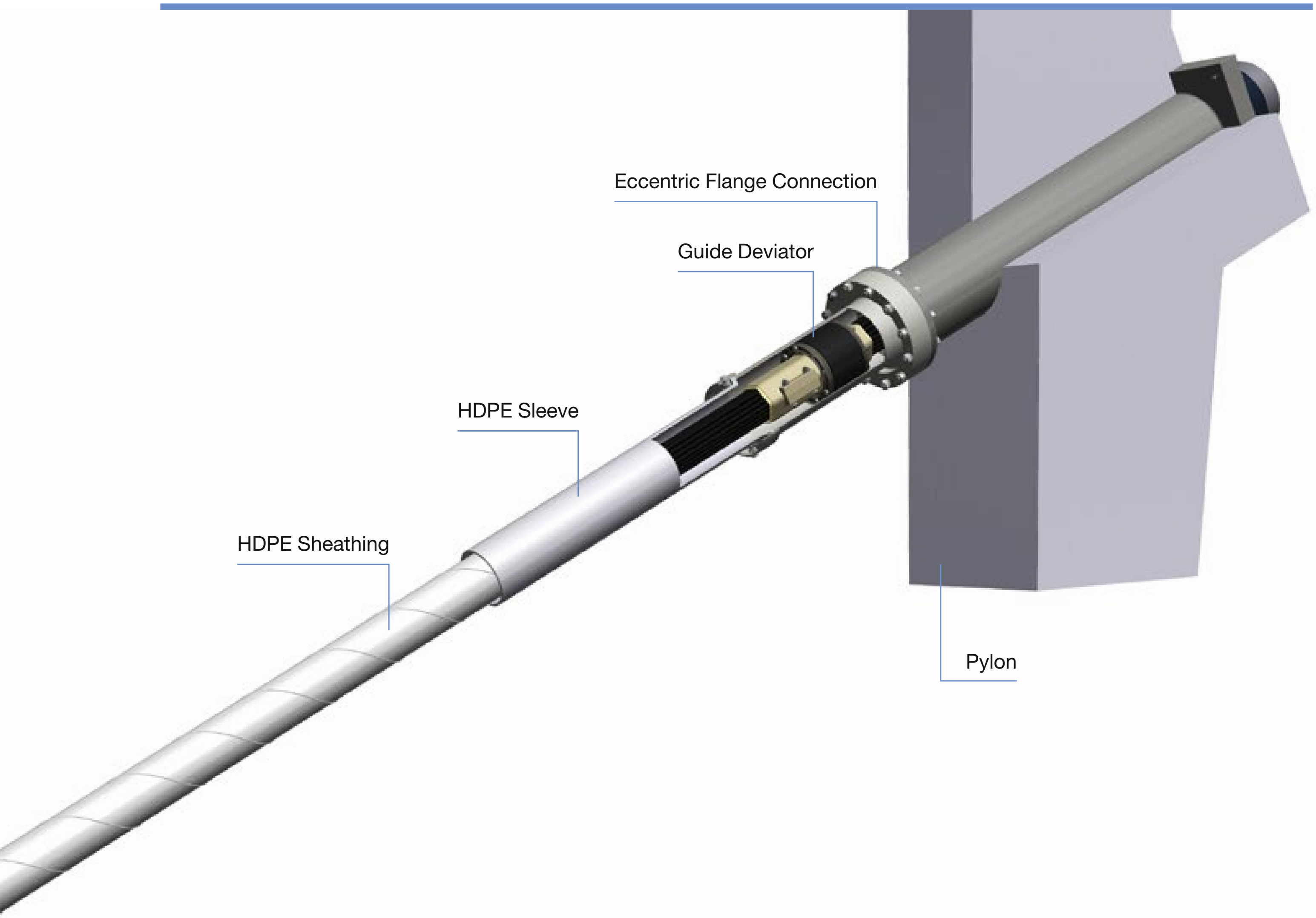
DG-P37	DG-P43	DG-P55	DG-P61	DG-P73	DG-P85	DG-P91	DG-P109	DG-P127
37	43	55	61	73	85	91	109	127
10,323	11,997	15,345	17,019	20,367	23,715	25,389	30,411	35,433
5,162	5,999	7,673	8,510	10,184	11,858	12,695	15,206	17,717
6,194	7,198	9,207	10,211	12,220	14,229	15,233	18,247	21,260
500	600	600	640	715	780	780	855	910
45	60	60	65	70	75	80	85	90
293	329	341	371	403	429	455	479	531
240	250	270	275	290	310	310	340	350
130	140	160	165	180	200	200	230	240
378	420	440	480	536	600	600	636	700
135	150	170	170	185	195	195	210	220
354	398	420	450	490	522	550	586	645
1,500	1,690	1,750	1,920	2,070	2,170	2,340	3,020	3,390
1,360	1,550	1,610	1,780	1,930	2,020	2,200	2,880	3,250
180	200	200	225	250	280	280	315	315

DYNA Grip® Stay Cable System – Optional Solutions

The DYNA Grip® Stay Cable System can be easily adjusted or upgraded if required:

- The length of the vandalism protection pipe can be adjusted to project specific requirements to achieve any requested height above the bridge deck level.
- On special request, guide deviators can be provided both at the deck and at the pylon to:
  - reduce cable bending at the anchorages
  - decrease cable vibrations
- DSI has patented an eccentric flange connection between the recess pipe and the housing for the guide deviator. The eccentric flange connection ensures that eccentricities caused by wrong installation angles of the recess pipe can be compensated.

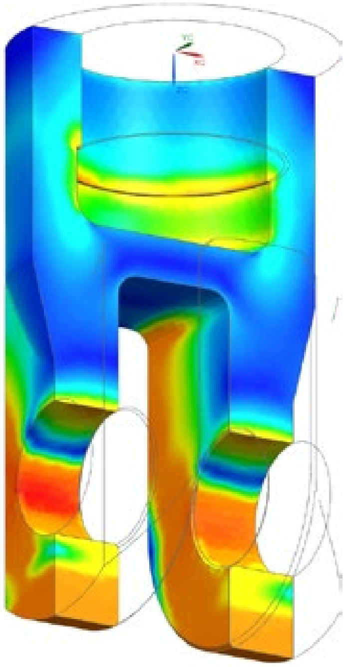



Eccentric Flange Connection
Guide Deviator
HDPE Sleeve
HDPE Sheathing
Pylon

DYNA Grip® Stay Cable System – Clevis Anchorage

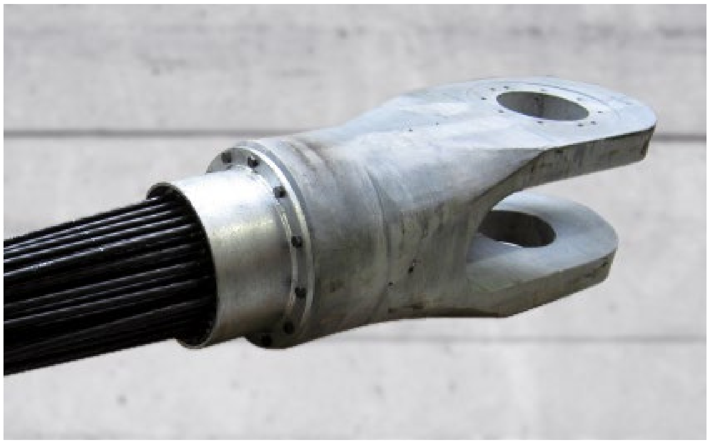
- Architectural requirements for the design of stay cable bridges are steadily increasing. Pylons often need to be as slim and elegant as possible.
- Solutions are needed in which the stay cables are connected to the structure outside of the pylon if the space inside the pylon is insufficient for common stay cable anchorages that are supported by bearing plates.
- DSI developed the DYNA Grip® Clevis Anchorage for strand cable types DG-P4 to DG-P61 as standard sizes with additional types on request, offering an economic alternative to conventional systems that have been used so far.
- The complete strand cable can be easily pre-assembled on the superstructure and is lifted into its final position afterwards.
- DSI offers special tools for the preassembly of the clevis as well as the mounting of the pin into the clevis hole.
- Restressing of individual strands as well as the replacement of the complete strand bundle is possible.
- This system also offers other DYNA Grip® System advantages.

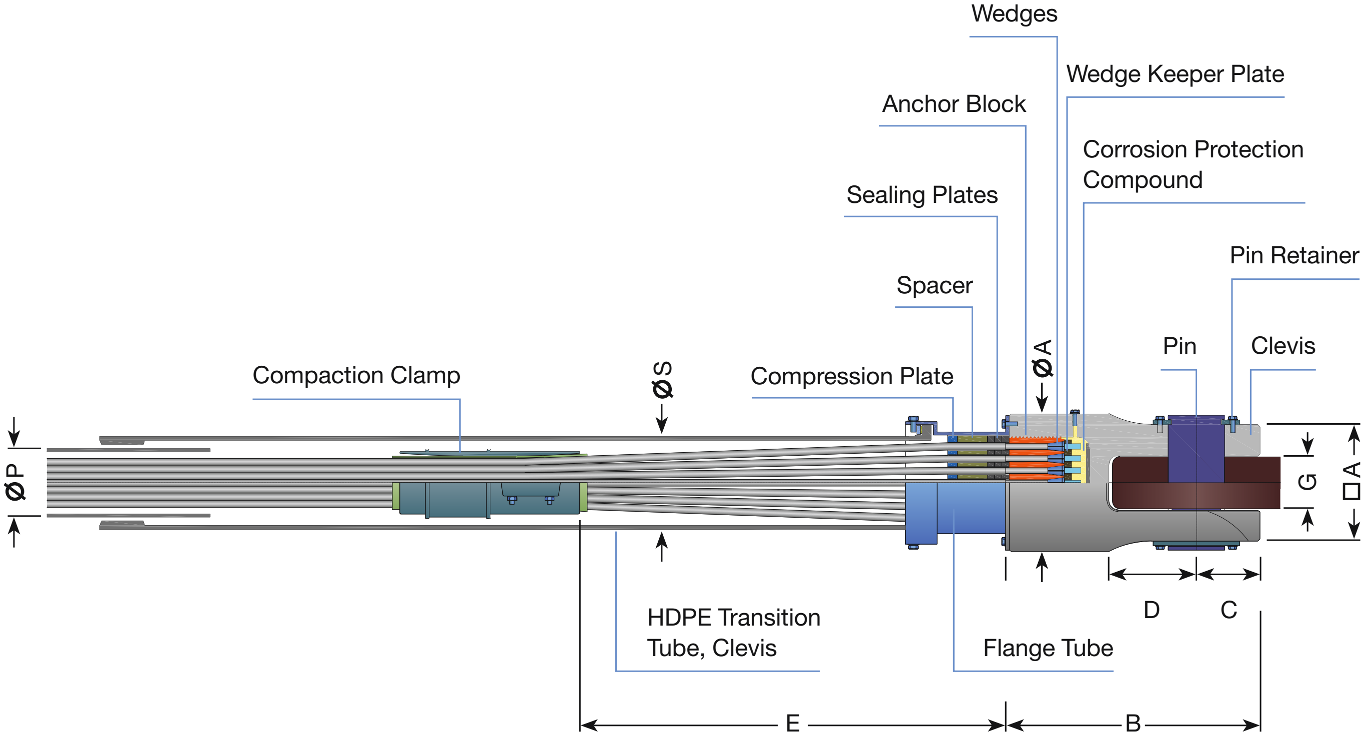
Fatigue tests were carried out at the Technical University of Munich in accordance with *fib* Bulletin 30 requirements. The tests respected an inclination of 0.6° – even towards the inflexible centerline – and an upper load of 0.45 GUTS. They were carried out with a stress range of 200N/mm² at 2 million load cycles.



These dynamic tests, as well as the subsequent static tensile tests, were performed with outstanding success.

The clevis anchorage is not only suitable for stay cable bridges, but can also be used for arch bridge hangers where available space in the arch is too small for aligning ordinary fixed anchors.





DYNA Grip® Clevis Anchorage – Technical Data

(forces calculated with strands 0.62" St 1620/1860)

Cable type*		DG-P 4	DG-P 7	DG-P 12	DG-P 19	DG-P 31	DG-P 37	DG-P 43	DG-P 55	DG-P 61
No. of strands		4	7	12	19	31	37	43	55	61
Forces [kN]**										
Ultimate load at 100% GUTS		1,116	1,953	3,348	5,301	8,649	10,323	11,997	15,345	17,019
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Service load at 60% GUTS for extradosed tendons		670	1,172	2,009	3,181	5,189	6,194	7,198	9,207	10,211
Dimensions [mm]										
Clevis	Ø A	140	200	230	270	330	355	390	415	450
Clevis	□ A	110	140	195	230	290	315	340	375	400
Clevis length	B	330	370	480	580	685	720	770	875	890
Clevis	C	60	75	100	127	158	170	185	212	220
Clevis	D	85	105	140	175	220	235	255	295	305
Distance of compaction clamp	E	400	510	740	940	1,210	1,360	1,550	1,610	1,780
Gusset plate	G	52	68	90	105	130	145	165	180	200
Gusset plate hole	Ø R	52	67	87	112	140	152	170	187	194
HDPE transition tube, clevis	Ø S	110	140	200	225	280	280	315	355	355
HDPE sheathing	Ø P	63	90	110	125	160	180	200	200	225

* Bigger size on special request
** Load design guidelines have to be considered

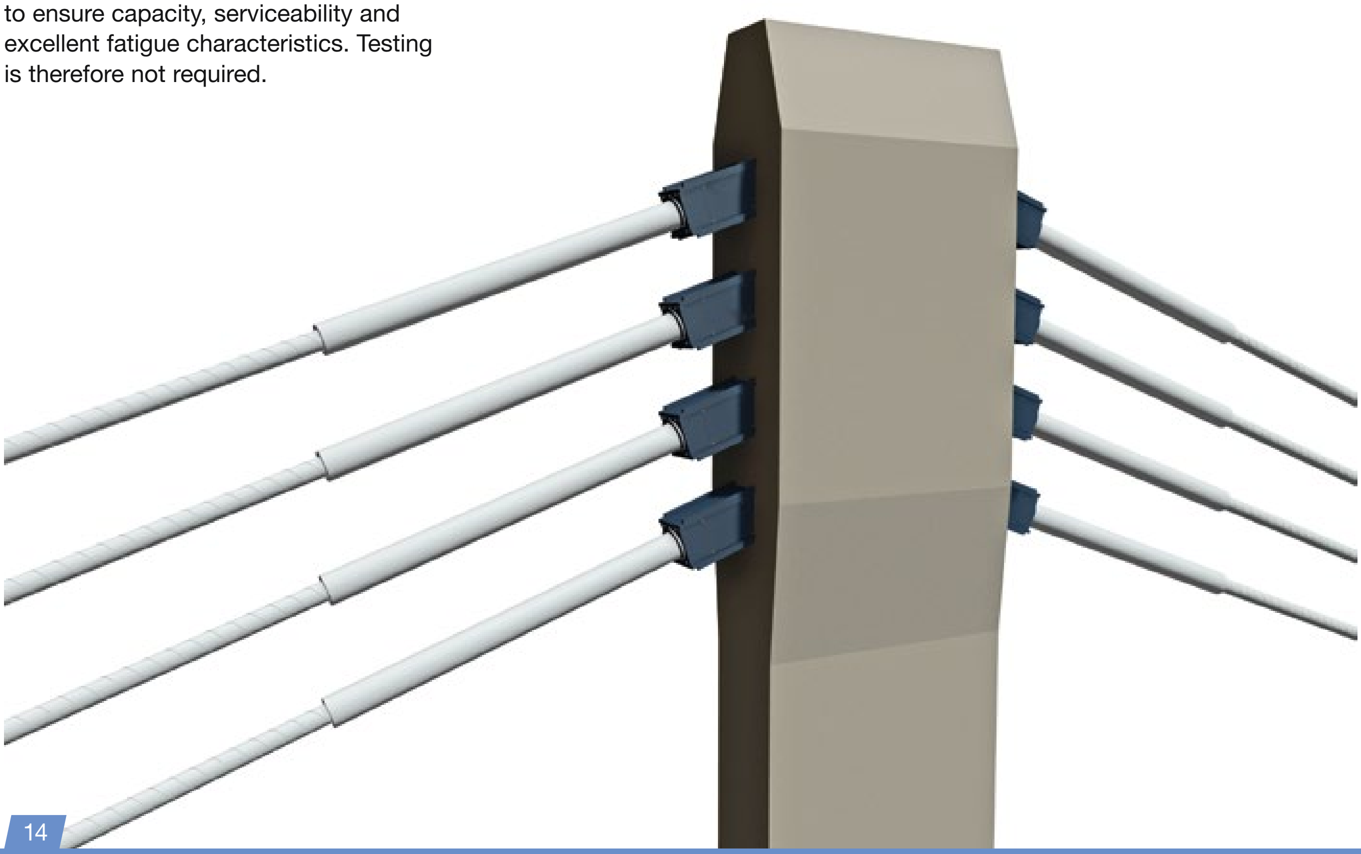
DYNA® Link Anchor Box System

DYWIDAG's DYNA® Link Anchor Box System is based on a conventional steel structure in which stay cables are anchored with standard DYNA Grip® anchorages. It features many advantages in comparison to conventional saddle solutions in which strands are guided through the pylon.

The key features of the DYNA® Link Anchor Box System are:

- No friction problems; horizontal forces are transferred by the anchor box
- Cable anchorages located outside permit slender pylon shapes
- The pylon does not need to be accessible
- Stay cable assembly is just as flexible as in the case of common stay cables with anchorages that are located inside the pylon
- It is even possible to replace a complete strand bundle only on one side of the pylon
- There are no limitations in terms of deviation radii or differential forces; consequently, no limitations in any national regulations need to be taken into consideration

The DYNA® Link Curved Anchor Box is economically designed using conventional steel construction standards to ensure capacity, serviceability and excellent fatigue characteristics. Testing is therefore not required.



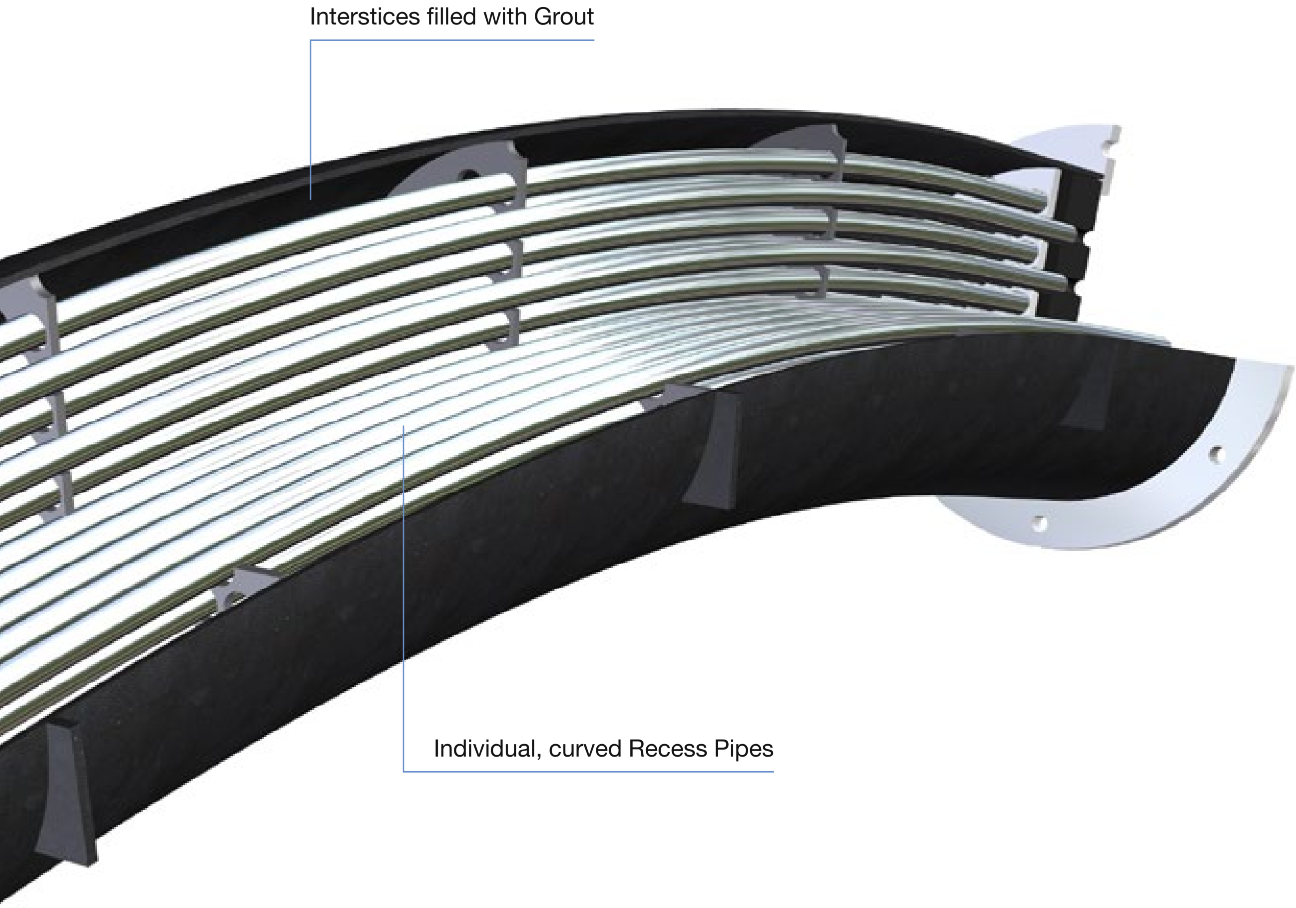
Saddle Solution

Saddle with Individual Tubes

If strands need to be guided through the pylon structure and a transfer of forces by friction is required, DYWIDAG offers a saddle in which the strands are guided from one side of the pylon to the other:

- Strands are placed into a multitude of individual, curved recess tubes. The interstices between the saddle tube and the recess tubes are grouted
- The saddle itself is embedded into concrete
- Individual strands can be replaced
- Differential forces are transferred by friction

Saddle Solution



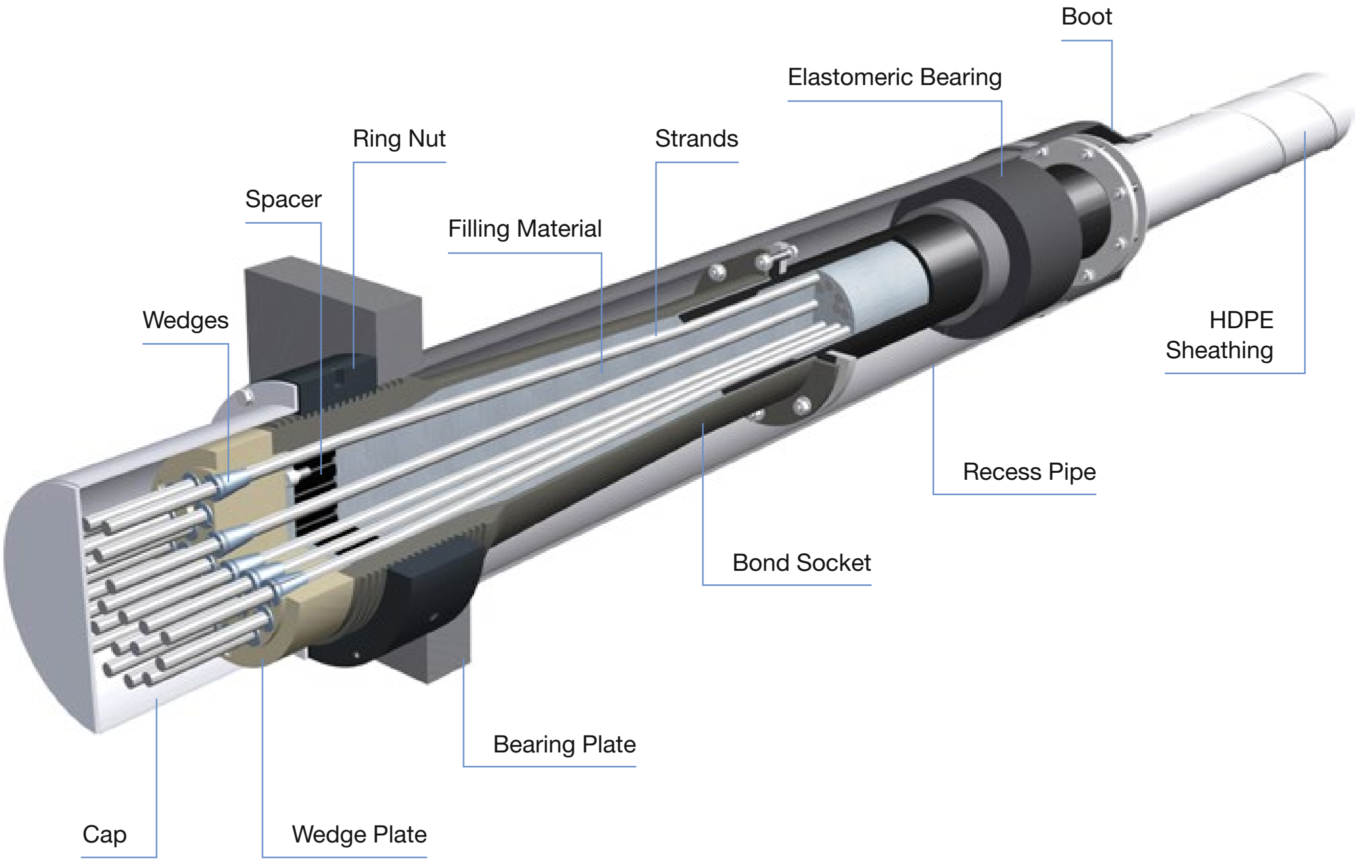
DYNA Bond® Anchorage

The DYNA Bond® Anchorage consists of a conical steel pipe (bond socket) supporting a wedge plate in which the strands are anchored with high-fatigue 3-part wedges. A ring nut is fitted on the threaded end of the bond socket and distributes the cable force through a bearing plate into the structure.

- During the construction period – prior to grouting the bond socket – all the applied loads are supported directly by the wedges
- At the final state of construction, all additional loads (live loads, vibrations and earthquakes) are partly resisted by both wedges and grouted bond socket.
- DYNA Bond® Anchorages have an excellent fatigue resistance because the bond action in the bond socket substantially reduces the magnitude of the dynamic loads reaching the wedge anchorage. Fatigue tests have proven a stress range of up to 240N/mm² at an upper load of 45% GUTS and 2 million load cycles.

Additional Advantages:

- Minimized bending effects at the anchorage by placing an elastomeric bearing inside the recess tube
- Reliable corrosion protection for the sensitive anchorage area, as all voids in the anchorage zone are filled with a stable and robust filler
- Enhanced fire resistance and protection against vandalism, impact loads and blast effects
- Easy fixation of external dampers directly on the grouted stay pipe
- A special patent protected sealing provision allows to grout the anchorage area only so that the free length remains without grout

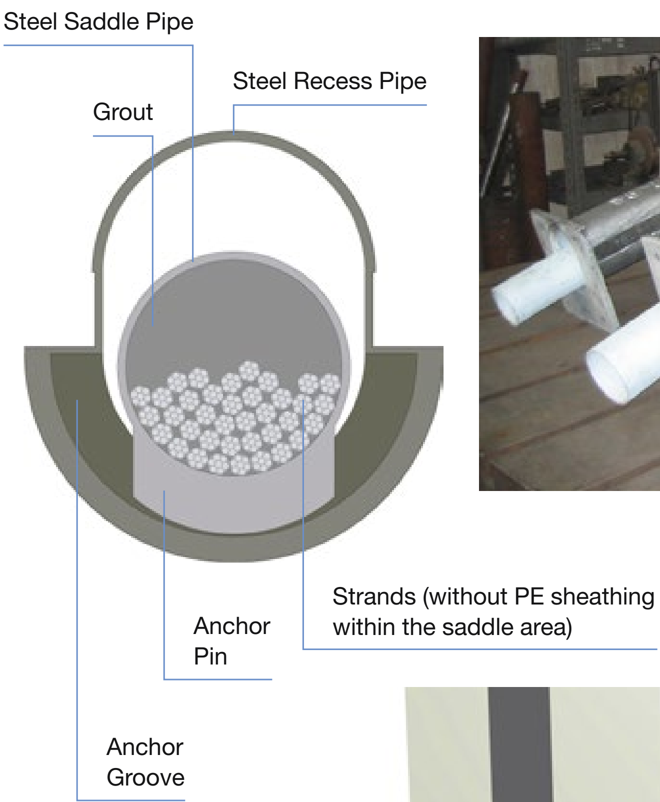


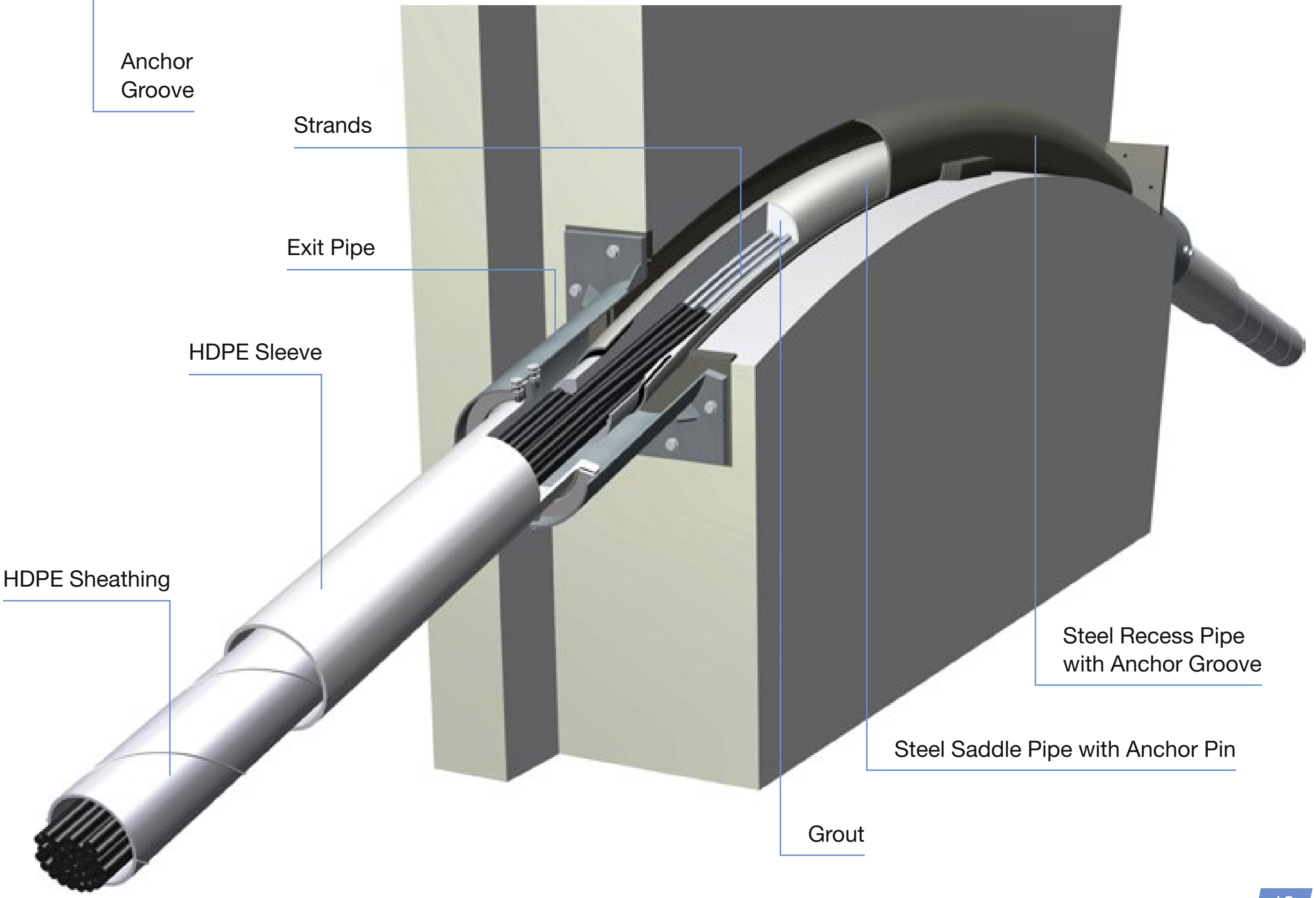
Fully Grouted Solutions

Saddle with Anchor Groove and Pin

The saddle transfers differential forces via a shear nose with pin into the pylon concrete construction.

- Strands (without PE coating inside the saddle) are guided in a curved tube and injected in the deviation area using special grout
- An inner, curved saddle pipe is guided through an outer recess pipe that is embedded into the concrete
- Differential forces in the stays at both sides of the saddle are reliably transferred via a shear nose (anchor groove – pin construction)
- The strand bundle including saddle pipe can be exchanged if necessary





Strand and Wedge

DYWIDAG Stay Cables use strands that meet the requirements of ***fib* and PTI-Recommendations** for stay cables, **ASTM, BS** as well as other national or international standards.

Generally, the following types of strands are used:

- 7 cold-drawn galvanized wires
- PE-coated with minimum thickness of > 1,5mm in accordance with *fib* Bulletin 30
- Wax as a void filler for the interstices between wires and PE coating
- Diameters up to 0.62" and steel grades up to 1,860mm²
- Low relaxation strand

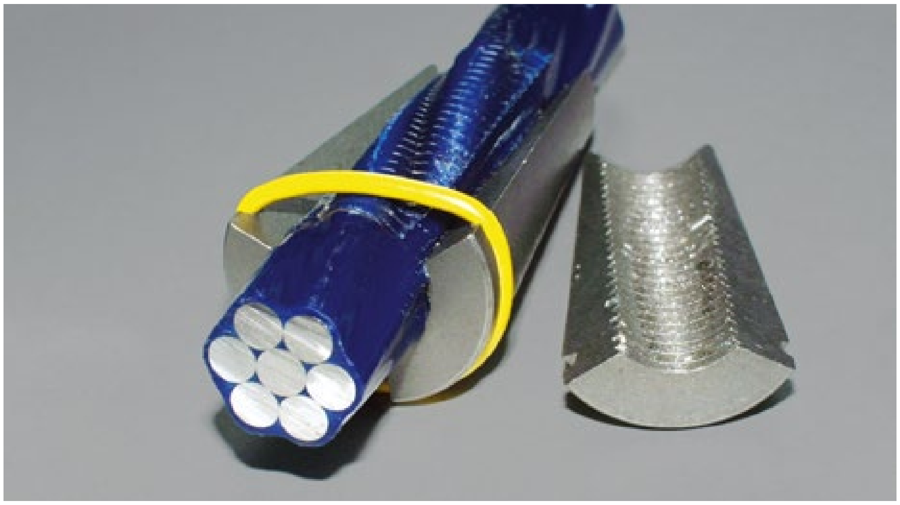
Strands are anchored with specially treated 3-part wedges that are characterized by high fatigue resistance.

Epoxy Coated Strands

Epoxy coated strand is manufactured in compliance with ISO 14655:1999. The 3-part wedges are specially designed for epoxy coated strands. The teeth penetrate through the coating so that they grip into the wires of the strand.

- Fatigue tests conducted on single-strand tendons have proven a dynamic stress range of up to 260N/mm² (upper stress 0.45 GUTS at 2 million load cycles).
- Cold-drawn 7-wire strand is coated with epoxy resin in the shop
- Interstices between the 7 wires are completely filled with epoxy resin, thus providing excellent and robust long-time corrosion protection.
- Epoxy material reduces fretting action between the individual wires and cushions adjacent strands in deviation areas
- The excellent bond of the epoxy with the steel wires and the ductile behavior of the epoxy material eliminate the possibility of damage to the corrosion protection barrier during stressing

Wedge for Galvanized Strand



Wedge for Epoxy Strands

Epoxy Coated Strand

Strand and Wedge

Outer Stay Pipe

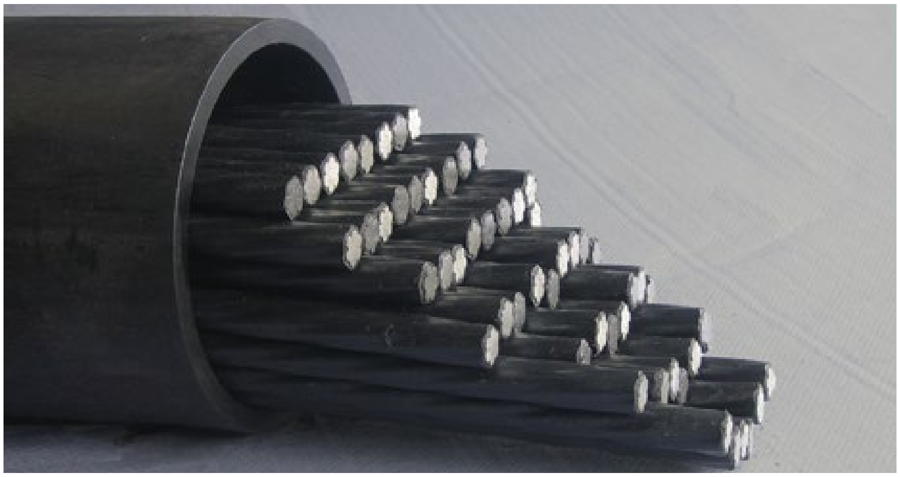
Standard Pipe

HDPE pipes serve as protection against environmental influences and are typically used as outer covers of DYWIDAG Stay Cables. Main characteristics:

- Wind load reduction at the cable
- Outer helix with demonstrated efficiency against rain-wind induced cable vibrations
- Co-extruded or fully colored pipes
- Wide range of colors
- The excellent UV-resistance has been proven in accelerated aging tests
- Steel or stainless steel pipes are available on special request

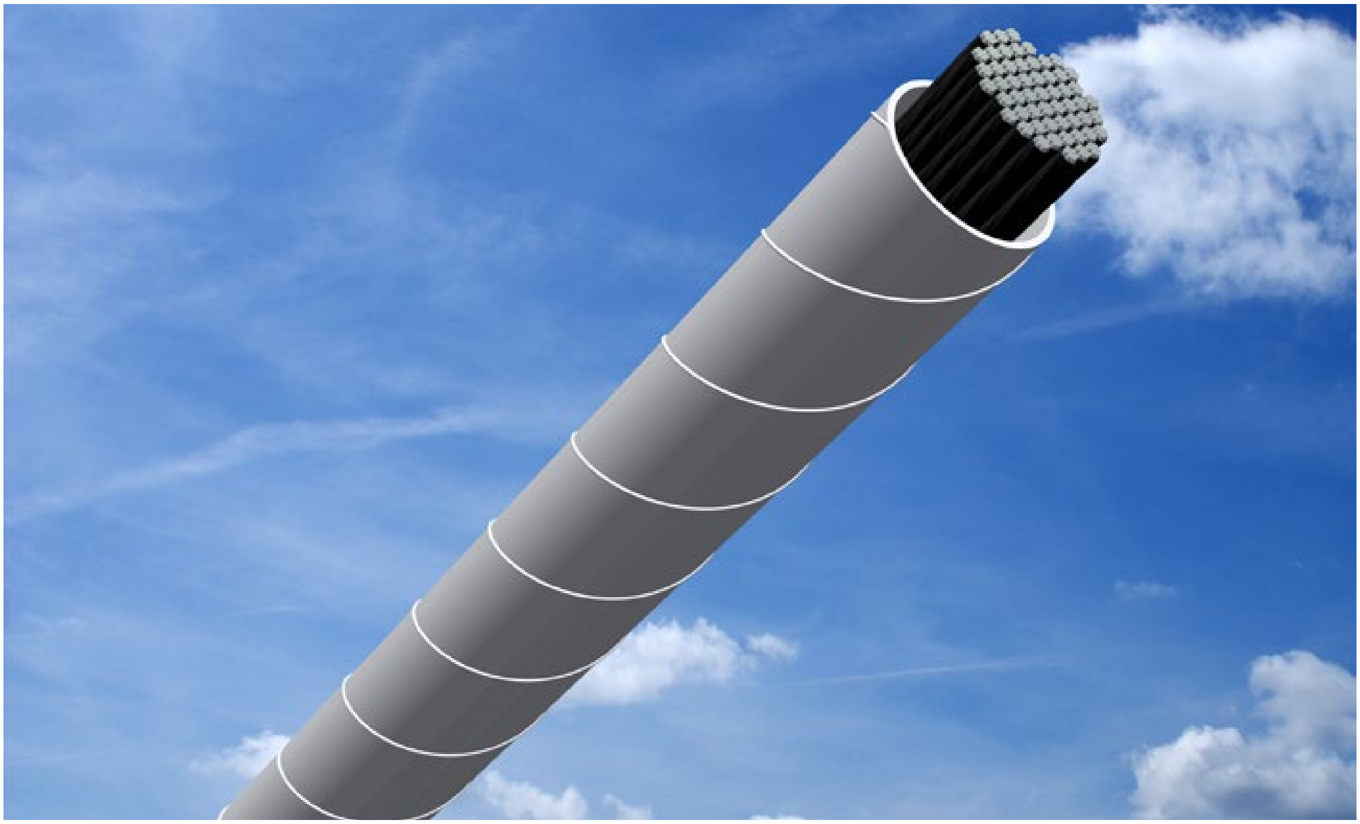
Slim Duct

For long span bridges, lateral wind loading at the cables needs to be taken into account for pylon design. To reduce the wind load, DSI offers slim sheathing with reduced pipe diameters.



Standard Duct

Slim Duct



HDPE Sheathing with Helix

Cable Damping

Slender supporting structures and long cable lengths make stay cables susceptible to vibrations. Big vibration amplitudes may result in damages to the cable due to bending and fatigue loads. This decreases a cable’s durability and may even endanger structural safety.

Depending on the respective cable parameters, each cable is more or less prone to vibration. Longer cables are more likely to vibrate than short ones. Nevertheless, cables with lengths above 200m have been installed without additional dampers without any vibration problems. On the other hand, even very short cables sometimes need dampers. By experience, DSI recommends to increase a cable’s inherent damping by using additional damping devices for cable lengths above 80m.

Cables start vibrating when they are excited. Please find following some excitation causes and methods for mitigating their effects.

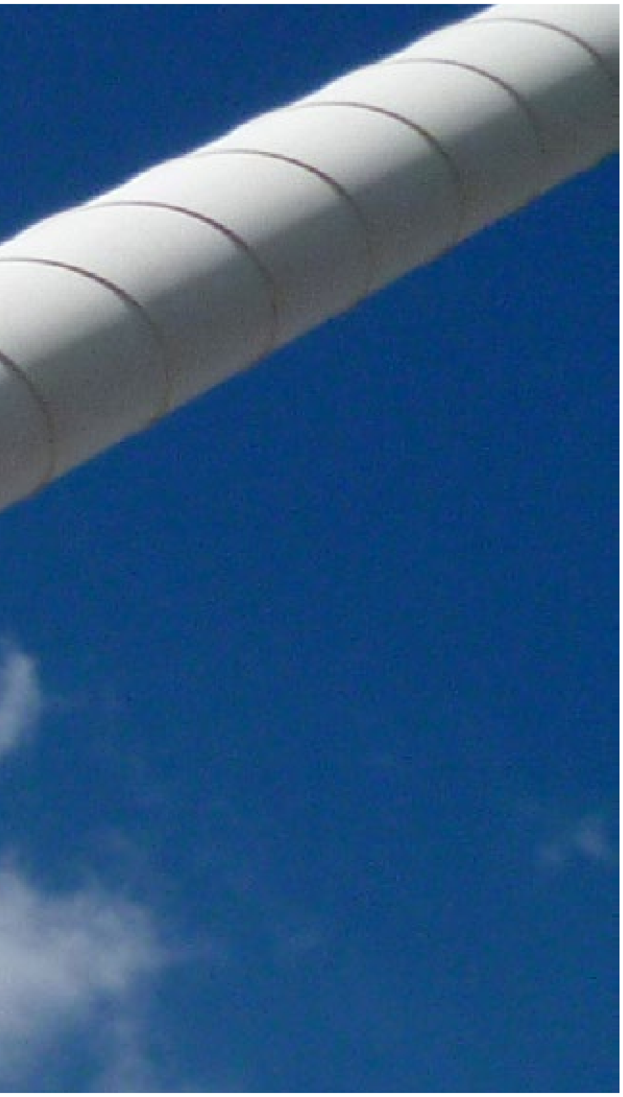
Excitation Causes

Buffeting

- Wind causes drag, lift and moment forces on cables that result in cable vibrations. Depending on the boundary conditions, inherent damping of a stay cable without additional damping might not be high enough to decrease these vibrations to an acceptable amplitude.

Vortex-shedding

- Uniform wind flow causes turbulent vortices to detach, alternating from a cable's top and bottom side, so that vibrations are caused. The amplitudes are usually small compared to the cable diameter. However, resonance of the vortex shedding frequency and cable eigenfrequencies can result in larger amplitudes.



Galloping

- Galloping affects rectangular shapes or round shapes with asymmetry. If the wind speed is above a critical value, vortexes detach from the edges and create similar effects as vortex shedding. However, contrary to vortex shedding, galloping results in high amplitude vibrations.

Wake Galloping

- Wake Galloping occurs at cables that are closely spaced in wind direction. Vortexes behind one cable excite the cable that is next to it and lead to vibrations.

Iced Galloping

- Ice that sticks to a round cable can alter its cross section in such a way that galloping occurs above a critical wind speed.

Rain-Wind induced Vibrations

- During specific combinations of rain intensity, wind speed, wind direction and cable inclination, water rivulets arrange at the cable's top and bottom surface. Due to wind, they move a few degrees around the cable circumference and induce vibrations into the cable. This happens at relatively low wind speeds.

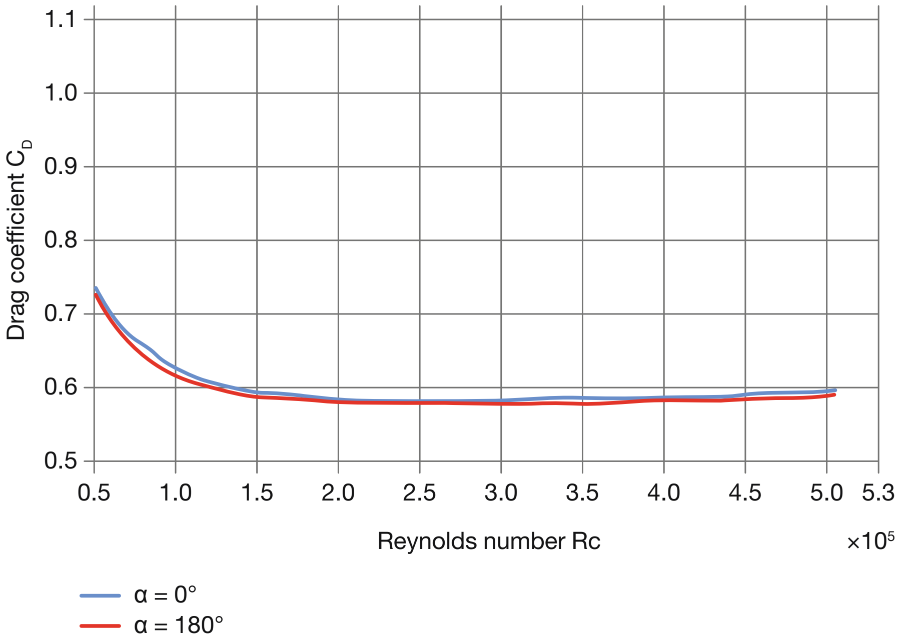
Parametric Excitation

- Parametric excitation is caused if the excitation acts on other parts of the structure (such as the pylon), and if this vibration is transferred into the cables.

DSI not only supplies the appropriate damping devices but also supports bridge designers and owners in choosing a damping concept that is customized to their specific project needs.

Outer Helical Fillet

- To mitigate rain-wind induced vibrations, a 3mm high double helical fillet is applied on the surface of outer stay pipes
- Different diameters have been tested in climatic wind tunnel tests
- Demonstrated drag coefficient of CD = 0,6 for large cable diameters



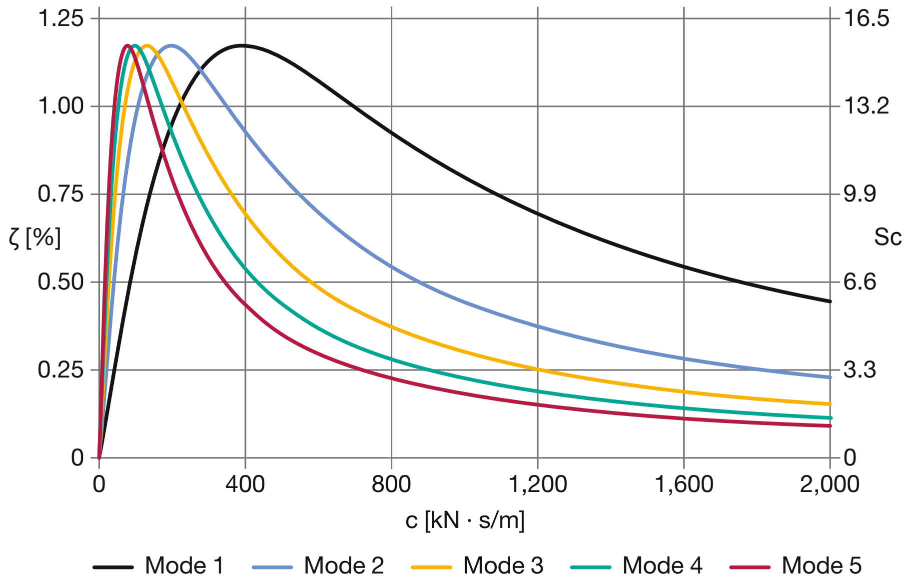
Damper Design

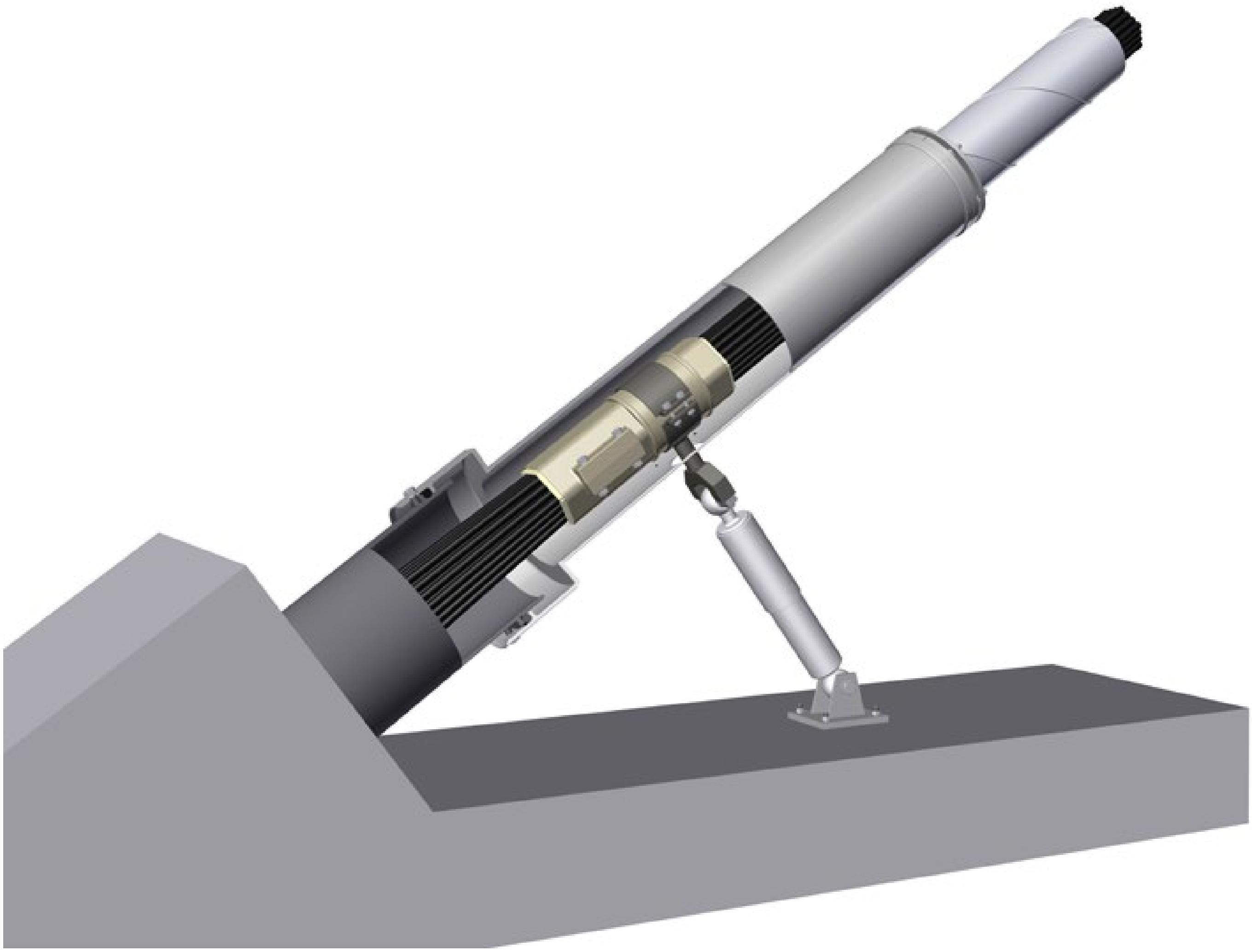
Sufficient damping prevents cables from vibrating. DSI recommends damping values of at least 3–4% logarithmic decrement δ, depending on each cable's boundary conditions and on project specific requirements. These damping values can usually not be achieved by inherent cable damping so that additional damping is required.

External Viscous Damper

External viscous dampers provide very effective supplementary damping.

- Special software developed for DSI
- Efficient dampers can be computed for each cable taking into account several vibration modes
- In plane, the damper is sufficient to also suppress out of plane vibrations
- Slender and aesthetic design; available in several colors





Internal Viscous Damper

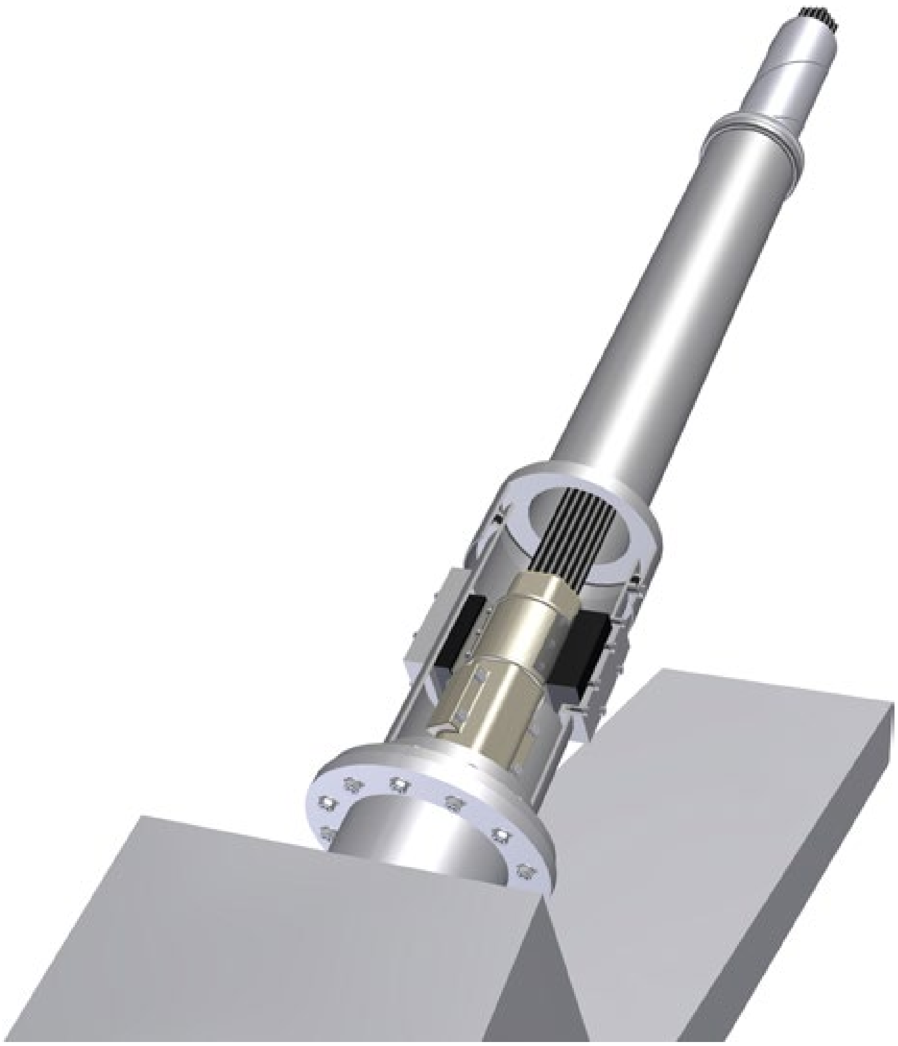
In addition to external viscous dampers, DSI also offers internal viscous dampers that are attached to the exit pipe.

- Damping forces are transmitted from the damper through its steel housing and exit pipe into the recess pipe, from where they are transferred into the superstructure
- Housed dampers are advantageous if support constructions would otherwise be needed to connect dampers and bridge deck
- Since DSI housed dampers do not require a connection point on deck, they can be used at virtually any cable position
- Increased durability is a benefit of housed dampers: they are not affected by weathering

Internal Rubber Damper

Especially used for short and medium cable lengths

- Internal rubber dampers are placed inside the exit pipe parallel to the cable axis
- Their elastomeric material dissipates vibration energy while deforming when subject to shear stress

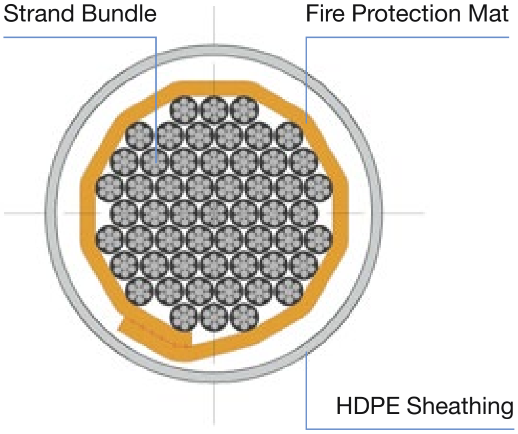


Fire Protection

Lightning, a car accident or other external incidents may cause fire on a bridge. In that case, the main parts of the stay cable system need to be protected against damage.

Fire Protection Mats for the Free Cable Length

- Special fire protection mats resist a hydrocarbon fire with 1,100°C for at least 30 minutes without heating up the strands to more than 300°C and with no permanent decrease in load capacity
- Used for the free length of the stay cable
- Covered by standard HDPE sheathing
- Mats have a hydrophobic behavior to avoid water absorption
- Possible upgrade for blast protection

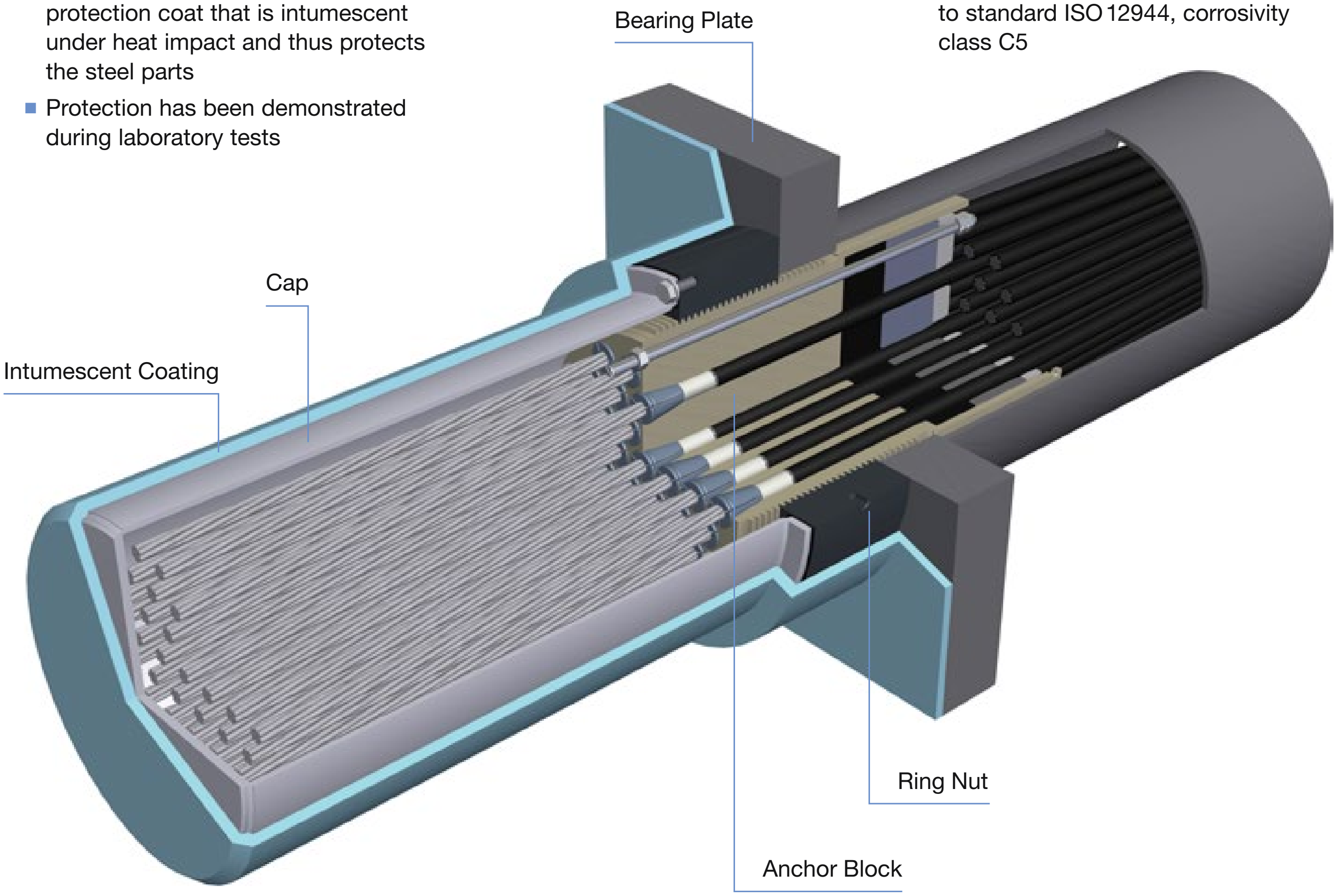


Fire Protection

Anchorage Area

- Steel parts in the anchorage area can be coated with a special fire protection coat that is intumescent under heat impact and thus protects the steel parts
- Protection has been demonstrated during laboratory tests

- Fire protection coating fulfills the highest requirements according to standard ISO 12944, corrosivity class C5



Anchorage Protection System

Coating before Fire Testing

Intumescent Coating after Fire Testing

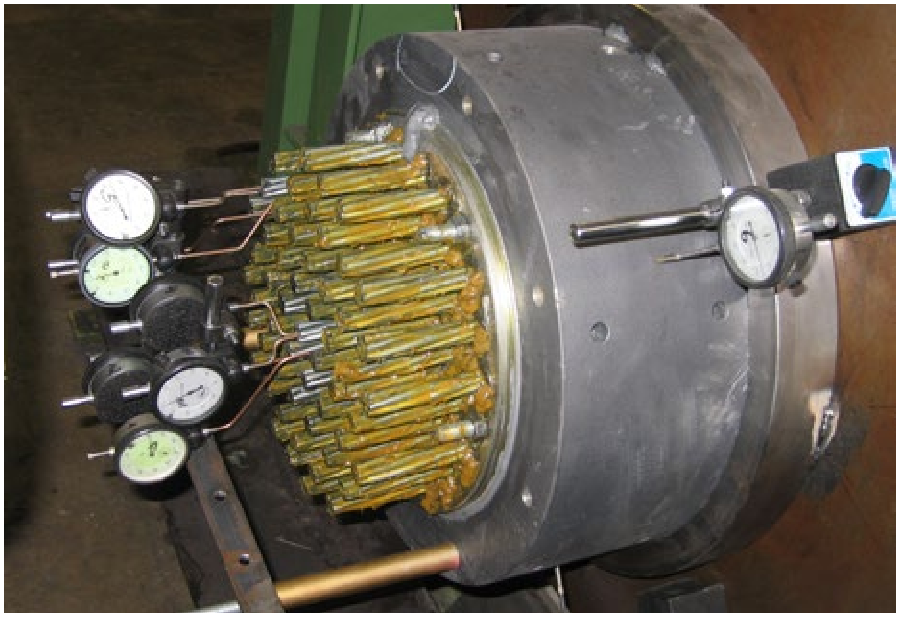
Full Size Testing

DYWIDAG Stay Cables have been successfully tested in static and fatigue tests in compliance with *fib* and/or PTI recommendations. Tests have been conducted in collaboration with renowned Universities such as CTL, TU Munich, TU Vienna or DTU Copenhagen.

Fatigue and Tensile Testing

- Applying 2 million load cycles
- Stress range of 200N/mm²
- Upper load level of 45% GUTS
- Inclined anchorages of 0.6°

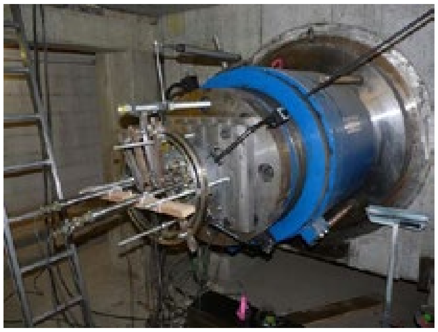
DYWIDAG Stay Cable testing has also been successfully conducted in additional full size tests with increased requirements in terms of upper load and additional angular deviation of the cable system

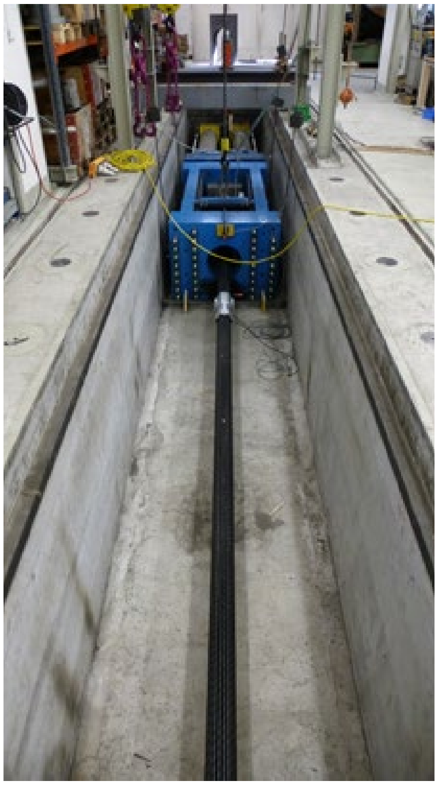


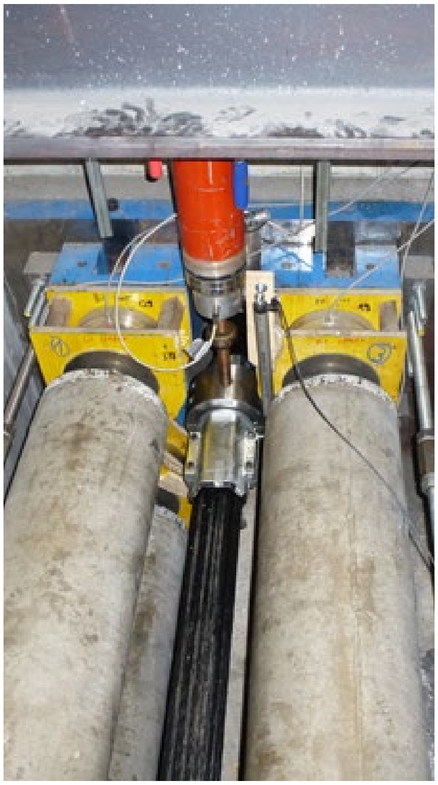
Full Size Testing

2 Million Load Cycles with additional Transverse Deflection

- Application of 2 million load cycles
- Stress range of 100N/mm²
- Upper load level of 60% GUTS
- Anchorages inclined by 0.6°
- Deviation of ±25mrad in transversal direction







Increased Load Cycle Testing – 10 Million Cycles

- Application of 10 million load cycles
- Stress range of 200N/mm²
- Upper load level of 45% GUTS
- Anchorages inclined by 0.6°

Monostrand Fatigue Testing under Reversed Cyclic Flexural Loading

A series of bending fatigue tests on galvanized, waxed and PE-coated 7 wire strands 0,62" with an ultimate tensile strength of 1,860N/mm² were successfully performed. They proved that the standard protective measures of the sealing unit within the DYNA Grip® Anchorage are effective for fatigue bending **without** the additional use of a guide deviator.

- Application of 2 million load cycles
- Different upper load levels varying from 45% to 60% GUTS
- Static inclination at the anchorage between 0,6° and 3.0°
- Additional angular deviation at the center of the strand between ±10mrad and 25mrad

Leak Tightness Test

DSI anchorages are fully resistant to any infiltration of water. Tested according to *fib* and Setra requirements with:

- Up to 3m water head
- Several load cycles in longitudinal and transverse direction
- Temperature cycle 20°C – 70°C

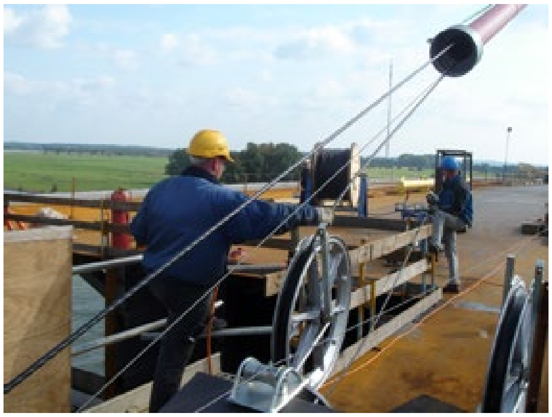
Cable Installation

DSI has developed various methods to optimize and simplify cable installation procedures depending on site specific space and time constraints.

- The outer sheathing is welded to its required length directly on site using heated tool welding and is then lifted into an inclined position
- Strands are uncoiled either from wooden reels or are provided reel-less. They are installed and stressed one by one using lightweight equipment
- Strand installation is performed using small winches or pushing devices
- Hardware configuration can be adjusted to site conditions to ensure a fast, customized solution that minimizes costs and cycle times

If required, the complete cable can also be preassembled on the ground first.

- Afterwards, strands are installed into the sheathing, and the complete cable is lifted into its final position
- Subsequently, all strands are stressed



Stressing

DYWIDAG stressing equipment is designed to ensure an economic and convenient installation process.

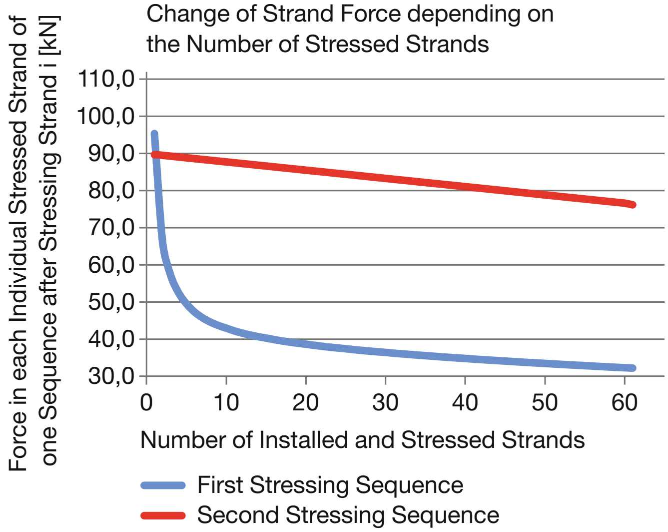
ConTen Stressing

The patented ConTen System uses a monojack that is hydraulically coupled with a control unit. The system is applicable both for DYNA Grip® and DYNA Bond® Stay Cable Systems.

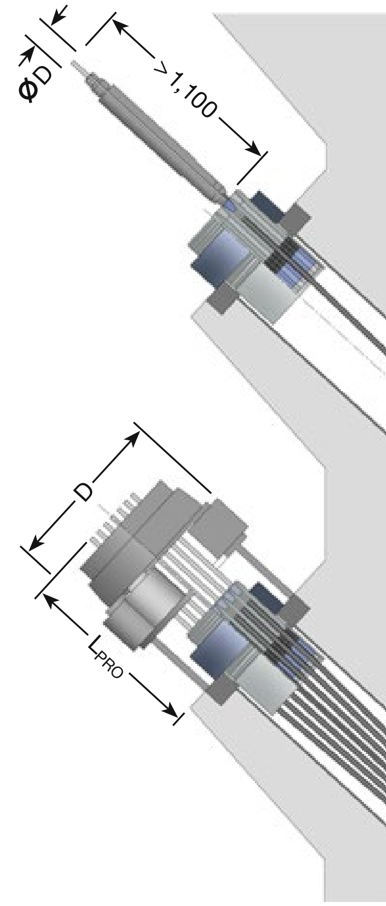
- Every single strand is stressed individually
- A special calculation method – developed by DSI – determines the force for the first strand and the corresponding forces for all subsequent strands
- This allows monitoring the stressing operation up to the required final cable force
- Equal forces are achieved in all strands within one cable at the end of the stressing operation
- Influences of temperature and load changes during stressing are automatically eliminated

In case of very short strand elongation values or if the cable force needs to be adjusted, retensioning or releasing of the complete cable is possible by turning the ring nut. Special compact **gradient jacks** are available for this purpose.

- Gradient jacks may be moved fully assembled or disassembled into their main components so that they fit even through small openings
- The same economic type of hydraulic pump can be used for both stressing systems. The pump is light, robust and has proven its reliability in many stay cable projects



Stressing



Jack type	Cable size	Type	Capacity [kN]	D [mm]	L_{PRO} [mm]	Weight [kg]	Strand protrusion L_{PRO} [mm]
ConTen Jack	All Types	180 kN	182	∅ 73	950	19	1,100
Gradient Jacks (DYNA Grip® **)	12 19 31	C 27	3,500	560 × 610	725	400	540*
	37	C 37	4,200	610 × 610	820	520	660*
	55 61	C 61	6,800	700 × 700	865	700	680*
	73	C 73	8,400	780 × 760	965	820	780*
	91	C 91	11,000	870 × 870	1,213	2,100	890*
	109 127	C 127	16,000	1,160 × 1,046	1,178	3,100	995*

* measured from the top of the bearing plate
** for multistrand jacks for DYNA Bond®, please contact DSI


Gradient Jack

Standard Hydraulic Pump

DYNA Force® Elasto-Magnetic Sensor

This system has been developed to measure or monitor forces within single strands of a stay cable during the construction progress as well as during the entire service life.

Functional Principle

- The permeability of steel to a magnetic field changes with the stress level in the steel
- By measuring the change in a magnetic field, the magnitude of the stress in the steel element is obtained
- Data is gathered and elected by special system components
- Data can be handled using a conventional computer

System Components

- Portable Power Stress Unit
- Sensor with lead wire
- Multiplexer Box for connecting more than one sensor to the Power stress Unit at the same time
- Automated measurement on several sensors through multiplexer
- Transfer of data by WLAN connection or cellular wireless connection

System Advantages in Comparison to other Measuring Systems

- The system cannot be overloaded
- Maintenance free
- No direct contact between the sensor and the strand/bar
- Resistant against dust and humidity
- Up to 2% of measurement accuracy

Quality Assurance

- All DYNA Force® Sensors are professionally made in a quality controlled facility
- Every DYNA Force® Sensor is tested and individually packed and numbered at the DSI facility before it is sent to the job site
- DSI has carried out additional tests to simulate the performance of the system when placed within the anchorage zone of stay cables

Practical Applications

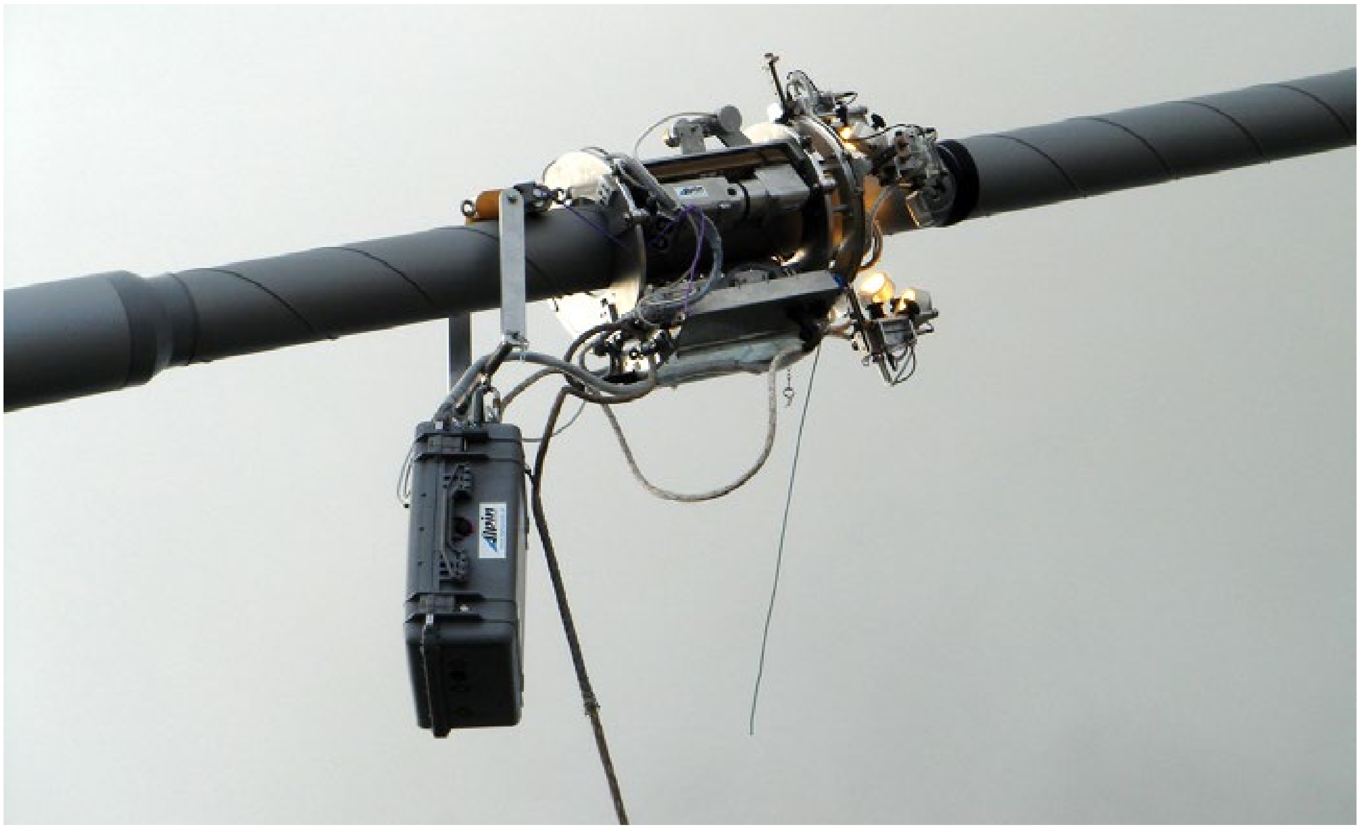
- When a DYNA Force® Sensor is installed on a strand, the force in it may be obtained directly by merely attaching the leads from the sensor to a portable Power Stress Unit
- No other equipment is needed
- DYNA Force® Sensors have been used in many bridge and building structures for the past several years

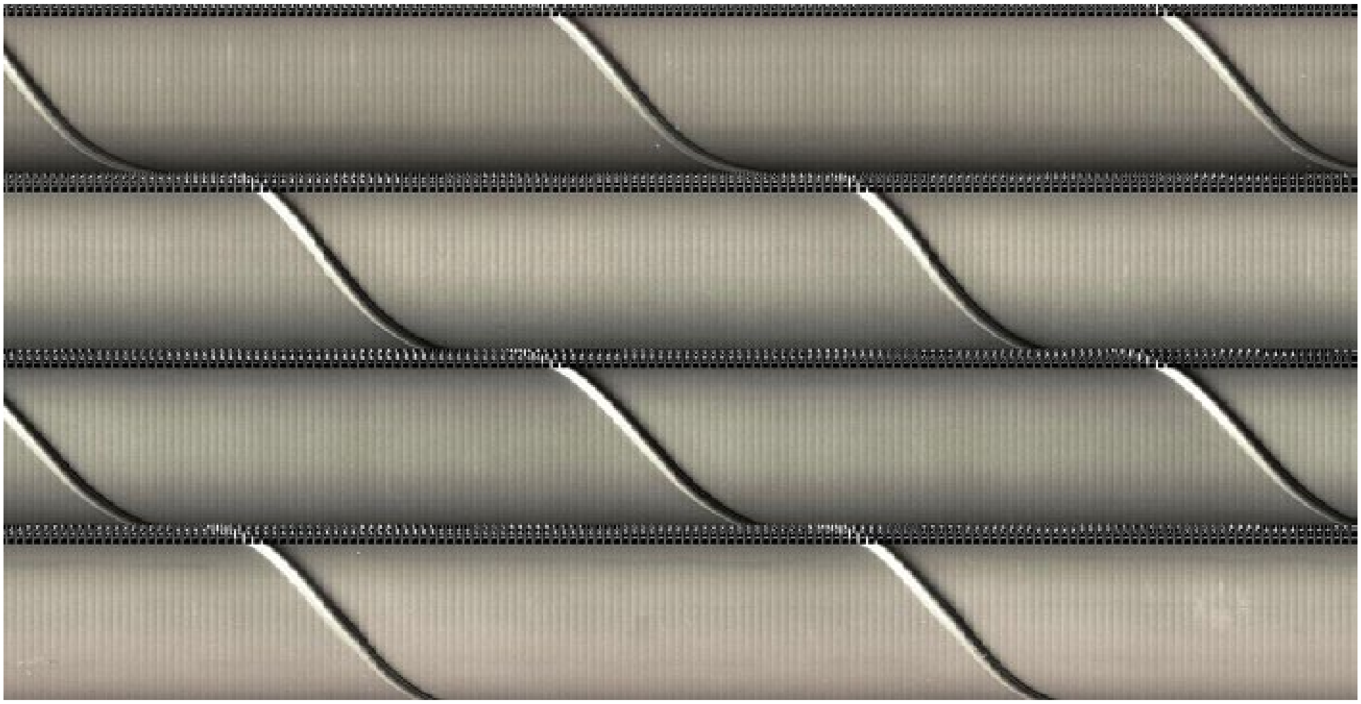
Cable Inspection

Visual Inspection

Visual inspection is a key measure during cable maintenance and inspection

- DYWIDAG visual inspection keeps traffic disturbances to a minimum
- Cameras are placed on an automotive cable robot that moves along the outer surface of the cable sheathing
- Cable surface is checked for damages or color changes
- Possible defects can be detected quickly
- Afterwards, detailed examinations can be limited to critical spots





Vibration Measurement

Cable forces and cable damping values are very important both during and after construction as well as for monitoring. DSI offers vibration measurement for tension members to quickly and efficiently determine both cable forces and damping values.

- A 3-dimensional accelerometer, placed on the cable, registers its movements
- Measurement at one cable only takes a few minutes
- Each cable has an individual vibration characteristic depending on cable force, dimensions, the type of anchorage and on possible cable supports
- Eigenfrequencies and eigenmodes correspond to the vibration characteristics and can be calculated from the vibration measurement
- The obtained cable eigenfrequencies are used to calculate tensioning forces
- Damping values can be calculated by determining the decay of vibration amplitudes

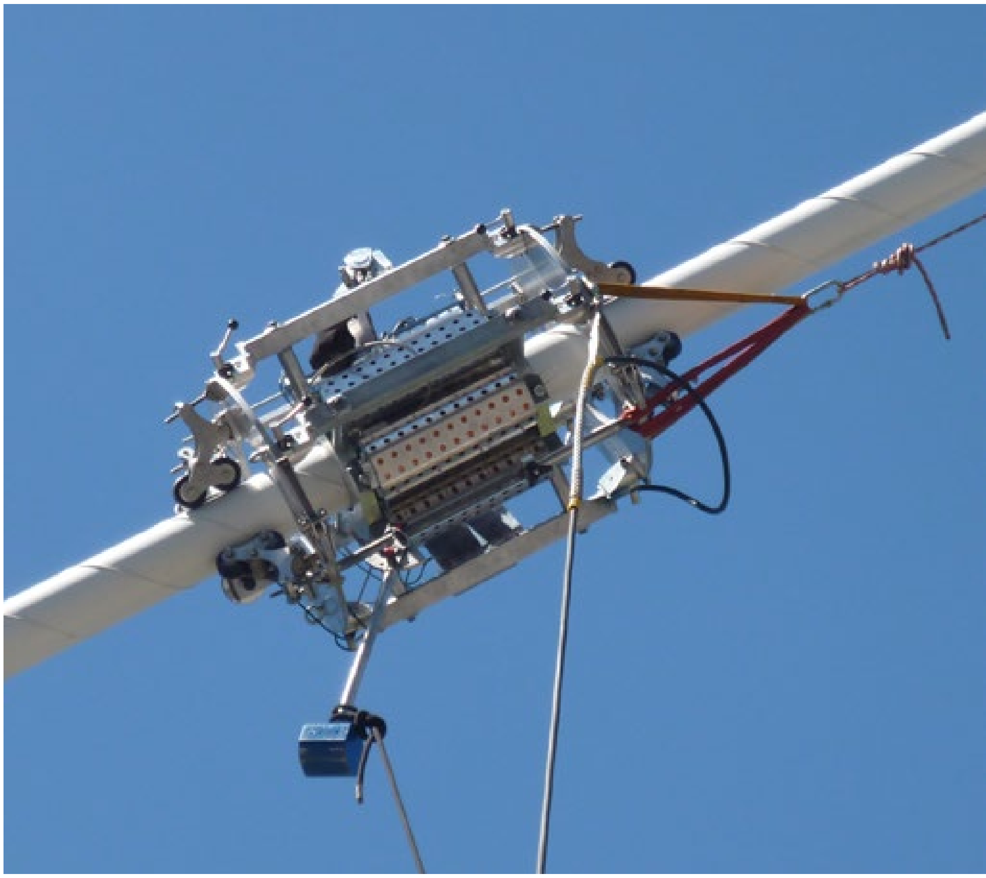
Magnetic Flux Leakage Inspection

Magnetic flux leakage inspection is a non-destructive testing method that detects changing magnetic properties. DSI uses this method to determine corrosion, breaks or cuts to strands.

Magnetic flux leakage inspection is a very economic and fast testing procedure:

- The equipment can be adapted to fit different pipe diameters
- Only the deck anchorage needs to be accessible for mounting the equipment. The measuring equipment is moved by hoists and winches in the free cable length, thus minimizing traffic disturbances
- The whole strand bundle can be magnetized, which allows checking even strands on the inside

There is no need to remove HDPE sheathing: The equipment moves along the pipes, and the magnetic field permeates the HDPE sheathing.



Stay Cable References

Bridge over the River Waal, Ewijk, Netherlands
Design, supply and installation of 40 Type DG-P 73 DYNA Grip® Stay Cables as well as 40 Type DG-P 91 DYNA Grip® Stay Cables with slim duct sheathing. Supply and installation of external damper system

Dr. Franjo Tudjmann Bridge, Dubrovnik, Croatia
Supply and installation of 38 Type DB-P 27 and DB-P 61 DYNA Bond® Stay Cables. Installation of adaptive dampers

Elbe Bridge Schoenebeck, Magdeburg, Germany
Supply and installation of 36 Type DG-P 31, 37 and 55 DYNA Grip® Stay Cables. Magnetic flux leakage inspection and vibration measurements during compliance testing

References

Harbor Drive Suspension Bridge, San Diego, USA
Design, supply and installation of two main stay cables and DYWIDAG Strand Tendons, 12-0.6", 19-0.6", 37-0.6", 37-0.62" and 43-0.6" in stainless steel sheathings that were used as back stays

Pitt River Bridge, Vancouver, Canada
Supply of 96 Type DG-P 31 and DG-P 61 DYNA Grip® Stay Cables. Design, supply and installation of an external damper system

Sae Poong Bridge, Gwangyang, Korea
Supply and installation of 90 Type DG-P 55 and DG-P 61 DYNA Grip® Stay Cables; 24 Type DG-P 12, 37 and 61 Transversal DYNA Grip® Stay Cables with Clevis Anchorages; 6 Type DG-P 19 DYNA Grip® Tie-Down Cables; installation of external dampers

Extradosed Bridge References

Trois Bassins, La Réunion
Supply and installation of 34 Type DG-P 37 DYNA Grip® cables with fully grouted saddle. Rental of equipment and technical assistance on site. Fire protection over the full cable length

Domovinski Bridge, Zagreb
Design, supply and installation of 32 Type DB-P48 DYNA Bond® Stay Cables with fully grouted saddle

Považská Bystrica, Slovakia
Supply and installation of 56 Type DG-P 37 DYNA Grip® cables with fully grouted saddle. Rental of equipment

Photo reprinted courtesy of Doprastav, a.s., Slovakia

Earthquake Memorial Bridge, AJK, Pakistan
Design and supply of Type DB-P 19 and 27 DYNA Bond® Stay Cables with fully grouted saddle

Arch Bridge References and Special Applications

Lake Champlain Arch Bridge, USA
Design, supply and installation of
64 Type DG-P 7 DYNA Grip® Hangers

Aguascalientes Arch Bridge, Mexico
Supply and installation of 34 Type
DG-P 19 DYNA Grip® Hangers

Gajo Arch Bridge, South Korea
80 Type DG-P 12 DYNA Grip® Hangers

Wind Turbine, Vaasa, Finland
Design, supply and installation of Type DG-P 37 DYNA Grip® Stay Cables

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Apollo Arch Bridge over the Danube River, Bratislava, Slovakia
Supply of 66 Type DG-P 12 DYNA Grip® Hangers; technical support and rental of equipment

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