Stay cables
Cable stayed bridge over the Po river, high speed railway line Milano – Bologna, Piacenza (Italy)
Tensacciai started to develop its technology for cable stayed bridges in the eighties. The first small cable stayed bridge was built in 1988, leading the way to the development of the wedge-resin coated anchorage system that found its mature application in the bridge over the Garigliano river in Formia. Later on the technical solution with waxed, polyethylene coated strands was adopted, finding the famous application of the worldwide known Erasmus bridge in Rotterdam, with huge stays of 127 strands and lengths reaching more than 300 meters. Through the years, a continuous improvement has led Tensacciai to the construction of more than 40 cable stayed bridges, using its TSR stay cable system. One of the latest is the cable stayed bridge over the Po river, designed for the high speed railway line Milano - Bologna. It is the first known example of this kind of structure. New challenges are foreseen for Tensacciai in the incoming years: the most daring will be the erection of a cable stayed bridge over the Adige river in Italy with 169 strands stays, giving a maximum breaking load of more than 47.000 kN. At this moment Tensacciai is directly involved in cable stayed bridges projects with Companies or Subsidiaries in all five continents.
TSR Stay Cable System

Tensacciai TSR stay cable system has been designed and tested in order to guarantee high levels of performance with reference to fatigue behaviour and efficiency limits. Corrosion protection has been deeply investigated and approached: 4 layers of protection surround the main tension element, steel strand. They are made with galvanization, wax and hdpe coating of steel strands and the final enveloping of the entire bundle in a hdpe tube. Vibration control of stays has been solved through the use of different types of dampers, both internal and external.

System has been developed to ensure tight insulation from external agents, as to guarantee the lowest maintenance activity together with a proper lifetime. System allows full replaceability of stay and strands substitution.

Cable stayed bridge over the Garigliano river, Formia (Italy)
The TSR stay cable system consists of a bundle of parallel seven-wire steel strands, with nominal diameter 15.7 mm. Currently it is the most utilised type of strand, but the system has been easily adapted to be used with different kinds, including epoxy coated strand. According to a principle of modularity, stay cables of several sizes can be obtained, from the smallest (e.g. the 3TSR15) to the largest and more complex ones (e.g. the 169TSR15). Stays are used in single and multiple spans bridges, in arch bridges as hangers, but also in suspended structures and buildings.

As a specialized contractor with decades of experience in the field, Tensacciai is able to provide, through its Engineering Department, all services related to design, manufacturing, installation and monitoring of stay cables. Starting from the analysis of the whole structure, design of stays is carried out, with shop drawings and specifications for manufacturing, issue of installation procedures with loads and elongations checking, together with further engineering services. New and customized solutions are continuously released, in order to fit into different projects.

Tensacciai takes care of all the installation operations, with their own specialized teams and equipment, taking full responsibility and operating under ISO 9001 quality assurance system.
Stay components

Design of all the components of TSR system is based on severe requirements for materials and their performances, as requested by the most important international standards as Fib "Acceptance of stay cable systems using prestressing steels".

Main materials involved are:
- High-tensile prestressing steels as main tensile elements (according to prEN10138 section 1-4, NF A 35-035, ASTM 416M)
- Forged steels used for anchorages and structural ones for tubes and saddle components (according to EN 10083, EN 10025)
- Zinc or other corrosion-protective coatings on the prestressing steel or structural steel components
- Filling materials such as wax for the protection of strands and anchorages
- Polyethylene sheathing on prestressing strands
- High density polyethylene (hdpe) for free length stay pipes
- Rubber or poly-chloroprene rubber for guide deviators or damping devices

Steel strands

Stay cable technology foresees the use of seven-wires steel strands with a nominal diameter of 15,7 mm, characteristic tensile strength of 1,860 MPa, and a nominal breaking load of 279 kN per strand.

Low relaxation steel strands, according to prEN10138-3, NF 35-035 and ASTM 416M, have the following protections:

1. Hot dip galvanization
   - zinc coating: 250 ÷ 350 g/m²,
   - applied before final drawing of wires (no loss of ultimate strength)

2. Wax filling around and within wires
   - quantity of wax: 5 ÷ 20 g/m,
   - anti-corrosion layer provided with adhesion properties,
   - lubricating against fretting fatigue

3. Bonded hdpe coating
   - minimum thickness of 1,5 mm,
   - UV stabilized, shock resistant,
   - extruded on strand

Cable stayed bridge over the Guamà river, Belém (Brazil)
Anchorages

Anchorages have to guarantee the proper load transfer from the cable to the structure. Hence they must withstand severe load conditions, with dynamic actions due to vehicular traffic, and wind forces acting on the free length of the cable. For this reason they are continuously tested. Two kinds of anchorages are available: adjustable, provided with a regulation nut, and fixed. Both types can be used either on the pylon or on the deck, according to installation and project needs.

Strands are gripped inside anchorages with specially designed wedges, tested to the worst fatigue and efficiency limits. Adjustable anchorages allow regulation of loads anytime is needed, even during lifetime of the bridge with a special adjusting jack acting over the entire anchorblock. Anchorages are also adapted to be used at deviated stay configurations with saddles, for extradosed bridges.

Wax Box System

Wax box system is designed to create a sealed and hermetic chamber behind the anchorblock, where strands’ uncoated length is completely protected with wax injection. After strands installation and closing of tensioning operations, the device placed at the bottom of the chamber is packed, providing full tightness. Wax injection can then be performed, restoring the layer of protection lost with removal of hdpe coating, necessary for wedge gripping of steel strand. Wax box system has been designed to be directly assembled in factory on the anchorage, with saving of time during installation phases in the construction site.

Arch bridge in Dintelhaven, Rotterdam (The Netherlands)

169 strands TSR anchorage

Anchorages
TSR Stay Cable System

- Bearing plate
- Wax box system
- Anticorrosive compound – Wax
- Nut
- Protection cap
- Adjustable anchorage
- Injection tube
Wax box system
Galvanized, waxed and hdpe coated strand
Deviation system
Form pipe
Damper system
Antivandalisme / Telescopic pipe
Galvanized, waxed and hdpe coated strand
## Main dimensions

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<tr>
<th>N° of strands</th>
<th>Nominal breaking load Fpk [kN]</th>
<th>Maximum working load 45%Fpk [kN]</th>
<th>Maximum tested fatigue load range (200 MPa) [kN]</th>
<th>ØA1 [mm]</th>
<th>ØB1 [mm]</th>
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Adjustable anchorages dimensions shown allow a ±20% variation of the maximum permitted working load (45% Fpk) acting over the adjusting nut.
* diameter to be confirmed according to the project
** if bearing on concrete surface with fck = 36MPa and considering 60% of ULS load

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### Fixed anchorhead

- **D**: Diameter of the anchorhead
- **E**: Diameter of the form pipe (variable)
- **F**: Diameter of the antivandalism pipe
- **G**: Diameter of the HDPE pipe

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Form pipe - variable
Antivandalism pipe
H.D.P.E. pipe
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Adjustable anchorhead
Stay components

**Hdpe tubes**

High density polyethylene (hdpe) sheath covers stay’s free length, providing a further protection against external agents, including UV rays, to the bundle of strands. Hdpe pipe is the perfect solution to meet protection needs, according with European standard EN 12201.

Pipes are supplied with different thicknesses, diameters and colours, in tubes of a maximum length of 11.8 m. that are welded on site, with special equipments, by mirror welding to create the continuous final stay pipe. Weldings develop the same strength of the monolithic pipe section.

Three kinds of hdpe tubes are available:
- with a smooth external surface,
- with helical fillets on surface,
- with lengthwise fillets on surface.

The two last ones are recommended to reduce dynamic effects due to rain - wind interaction phenomena, decreasing the risk of stays’ dangerous vibrations.

Tubes can be provided in several different colours, meeting different designers’ aesthetic needs.
Vibrations’ control is very important to prevent dangerous phenomena of instability, amplification of loads and fatigue. Inside stay cables, it is assigned to proper devices.

Tensacciai elastomeric dampers are placed at the end of the form tube, near the connection with the antivandalisme tube or the telescopic tube.

Each stay is planned to have a couple of internal dampers, one in the area close to the deck and one up near the pylon.

The damper works when the level of the cable vibration becomes critical. This system is easily adaptable to all configurations and projects, and thanks to the high efficiency, durability and low maintenance costs, it is the best solution to reduce vibrations.

Durability is guaranteed by the high quality of materials and the anticorrosive treatment applied on all components.

Standard elastomeric damper comprises both a neoprene ring damper with steel disks support and a middle nylon disk providing deviation of each strand.

With neoprene deformability it is possible to absorb vibrations, maintaining a high serviceability of the structures in each situation.

A second type of damper can be provided, designed with a steel clamp compacting all strands together.

The interposition of a hdpe sheath between strands and clamp prevents from any possible damage, allowing a simple and safe installation sequence.

Damper is inserted inside an external steel tube, which allows to move the whole system on stay’s real axis on the bridge and fix it through special flanges: on site adjustment can be easily performed.
Installation

Installation of the TSR system is always carried out by worldwide experienced Tensacciai teams, taking care of all phases thanks to many decades of experience in the field. The fastest installation is also guaranteed by means of specially designed installation equipment.

Preliminary operations are the welding of the hdpe tubes to the final length and the cutting of strands, starting from coils, over special benches to reach right marked measures. With the anchorages already placed at pylon and deck level, the hdpe tube is lifted with a tower crane and the first strand is threaded with special winches, following a defined sequence.

Stressing is carried out while placing strands, one by one, with the use of a special Tensacciai monostrand jack, provided with system of measuring of loads and elongations.
This step is carried out using the iso-elongation principle: stressing is done reading the position of marks placed over strands, with guarantee of same load acting over the full bundle, through same position of marks. One installed the entire stay, further steps of stressing with monostrand jack may be carried out. Anyhow final small regulations of loads are performed with the use of a Tensacciai adjusting jack, acting directly over the adjustable anchorage and turning the nut till final position. Once completed stressing operations, injection of anchorages with wax is carried out after placing of protection caps. Then final closing of antivandalism and telescopic tubes is carried out.

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<th>Nº Strands</th>
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Saddle System

Through the years Tensacciai has been developing its technology for saddles, both for cable stayed bridges and extradosed bridges, in response to issues with existing saddle designs, relating to fatigue, fretting corrosion and replacement of the cables. One of the great advantages of the TSS system is that it allows designers to simplify the pylon structure and use very slender profiles to achieve an attractive appearance.

Two different kinds of saddles can be provided. The TSS-B type is composed of a rectangular steel box filled with a high-strength compound. Design ensures high friction between the cable and the saddle. Full cables can be replaced while strands can be tensioned independently during installation phases.

The new Tensacciai Saddle system TSS-T is a multitube saddle based on the use of protected strand which takes up the asymmetric frictional loads through the strands. Each strand is deviated individually in a specific tube, giving the following advantages:
- complete continuity of corrosion protection,
- possibility of individual replacement of strands,
- fatigue resistance identical to a standard stay cable anchorage.

Cable stayed bridge over the Loing river, Nemours (France)
Suspended bridges

Tensacciai suspended bridge system has been designed to use seven wire steel strands both for suspension cables and vertical hangers. Special strand, epoxy coated with silica powder and hdpe coated, is used for suspension cables, providing the highest level of corrosion protection. Vertical hangers are connected to suspension cables through special shape steel clamps, transmitting forces by friction. This system has been severely tested in order to verify ultimate limit shear loads and fatigue behaviour, providing excellent results. Connecting clamps allow hangers to adapt their position depending on actual geometry of the bridge during installation. Saddles on top of pylon have been designed in order to minimize shapes and manufacturing processes, starting from simple steel plates with right shapes.
Monitoring

Monitoring of stay cables is important during all service life of the bridge, and it becomes critical in many cases. Monitoring of loads can be carried out with the use of permanent load cells placed over anchorages. They can be of two different types:

- monostrand, where load cell is placed only over one strand of the anchorage and giving full load of the cable as extrapolation of the single strand load,
- annular, resting directly beneath the nut of the adjustable anchorage and providing readings of the load acting over the entire stay.

All load cells are designed to minimize the sensitivity to eccentric loads and bearing surfaces. They can be connected to an acquisition data system, providing summary of the readings taken from different cells. In such a way full monitoring of all stays can be performed, giving a real time situation of the bridge during lifetime.

Further monitoring systems can be provided, like the innovative radar detection system, that allows checking of loads and displacement through interferometric radar devices. This new cheaper system guarantees proper readings and reduced jobsite activities.
Testing

Through the years an imposing test campaign on stay cables has been carried out by Tensacciai. Tests have been carried out not only over full scale assembled cables but also over single devices, like wedges, anchorages and dampers. Italian and International worldwide known laboratories have been chosen for testing, such as the EMPA laboratories in Zurich (Switzerland), the European Community JRC in Ispra (Italy), the University of Munich (Germany). Tests have been performed according to International Standards like the PTI Stay Cables Recommendations or FIB Acceptance criteria for stay cables. Sizes of cables tested varies from 16 up to 91 strands, not only with axial set up but also with deviated one. Stays have been submitted to deviated fatigue tests, with stress range of 200 MPa and pulsating transversal displacement leading to cyclic angular variation of 0,5°, repeated more than 2 million times. Results have shown excellent fatigue resistance, with cross section of stays withstanding wire breakages far below 2%. Subsequently stays have been brought to failure, performing the usual efficiency tests: results of more than 95% of nominal breaking load of the cable have been achieved. Testing campaign is still on the run, to check new design choices and improve products and performances.
Cable stayed bridge over the Po river, high speed railway line Milano – Bologna, Piacenza (Italy)
Cable stayed bridge Otavio Frias de Oliveira over the Pinheiros river, Sao Paulo (Brazil)

Cable stayed bridge over the Sangone river, Giaveno (Italy)
Cable stayed bridge over the Sergipe river, Aracaju (Brazil)

Cable stayed bridge Erasmus, Rotterdam (The Netherlands)
Bridges

Arch bridge over the Twente channel, Eefde (The Netherlands)
Cable stayed bridge over the Paranaiba river, Carneirinho (Brazil)

Cable stayed bridge Jura overpass, Desnes (France)
Cable stayed bridge Kwanza, Barra do Kwanza (Angola)
Cable stayed bridge over the Guamá river, Belém (Brazil)
Arch bridge Shaikh Khalifa Bin Salman, Hidd (Bahrain)
Bridges

Cable stayed bridge in Alves, Bressanone, (Italy)
Footbridges

Footbridge in Jesolo (Italy)
Footbridge in Melegnano (Italy)
Footbridges

Footbridge in Gemelli hospital, Rome (Italy)

Footbridge in Vaiano (Italy)