

## SECOND STRELASUND CROSSING EXAMPLE OF APPLICATION OF UP-TO-DATE PRESTRESSING METHODS

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### Abstract

The second Strelasund Crossing is currently the largest bridge building project in Germany. The outstanding structural element of the 2.830 m long structure is 583 m long stay-cable bridge with a main span of 198 m across so-called Ziegelgraben that has 42 m high opening for ships to pass through. Remarkable in this connection is the first-time use of parallel strand bundles made of galvanised, waxed monostrands instead of the previous fully locked cables. However, it may not remain unnoticed that the major part of the pre-stressing is executed using the mixed construction method with well proven pre-stressing systems in the subsequent bridge structure. Is the further development of these systems innovation or are there novel methods indeed?

### Streszczenie

Druga przeprawa nad cieśniną Strelasund jest obecnie największym mostowym projektem budowlanym w Niemczech. Wyjątkowym elementem konstrukcyjnym tego obiektu o długości 2830 m, jest most podwieszony o długości 583 m z głównym przęsłem długości 198 m przez tzw. Ziegelgraben. Most znajduje się na wysokości 42 m umożliwiając statkom swobodną żeglugę. Znamienne w tych warunkach jest wykorzystanie po raz pierwszy równoległych wiązek splotów wykonanych z galwanizowanych, woskowanych, pojedynczych splotów zamiast wcześniej używanych w pełni zamkniętych kabli. Nie należy zapominać, że większość sprężania jest wykonywana za pomocą metod konstrukcyjnych połączonych z systemami sprężającymi dobrze zbadanymi w kolejnych obiektach mostowych. Czy dalszy rozwój tych systemów jest tylko innowacją, czy może raczej są to nowe metody?

Keywords: CE Marking; Durability; ETAG 013; PT systems; Stay cables; Testing.

## 1. INTRODUCTION

The use of parallel strand bundles in the Strelasund Crossing construction project embodies an innovation that was successfully completed as a result of the cooperation of all parties involved in the project. Due to the lack of national guidelines, the new fib bulletin 30 [1] was adopted as a basis for testing pre-stressing systems for obtaining an approval in an individual project. The requirements specified for parallel strand bundles were much stricter than the hitherto applicable regulations for completely closed cables. Conducting large-scale trials tests turned out to be extremely challenging. Besides of being architectural striking, a special feature of the Ziegelgraben Bridge is the fact that for the first time in Germany

stay cables made of galvanised, waxed and PE-coated strands were used in a significant number instead of the locked-coil cables used until that time.

The steel superstructure with the height of 3.15 m and the width of 16 m features 2 main spans 198 and 126 m long. It is supported by 32 DYNA-Grip® stay cables, type DG-P 37 with 34 strands 0.62" St 1770 each. They are tensed from H-shaped, 87 m high steel pylon on top of a concrete pier 41 m in height. In this particular project the new fib recommendation was taken as a basis for the approval, since national guidelines for stay cables consisting of strands are nonexistent. All required testing was performed according to this standard. Start of the construction was in autumn 2004 with the completion date in October 2007 (Fig. 1).



**Figure 1.**  
**Ziegelgraben Bridge**

## 2. STAY CABLES

### 2.1. Description

32 DYNA-Grip® stay cables, type DG-P 37 with 34 strands 0.62" St 1770 each support the superstructure in the area of the large spans. In the anchorages there is space for three additional strands for subsequent strengthening if required. On the side of the superstructure the stay cables are equipped with a stressing anchor (Fig. 2), consisting of an anchor block with an adjustable ring nut, and on the side of the pylon with a dead end anchor. All anchorages feature internal sealing elements that prevent the ingress of water into the wedge area.

The 7-wire cold-drawn, galvanized and waxed strands with a PE-sheathing are anchored using 3-part wedges with high dynamic performance. The entire strand bundle is enveloped by an aluminium coloured HDPE protective casing with an external helix.

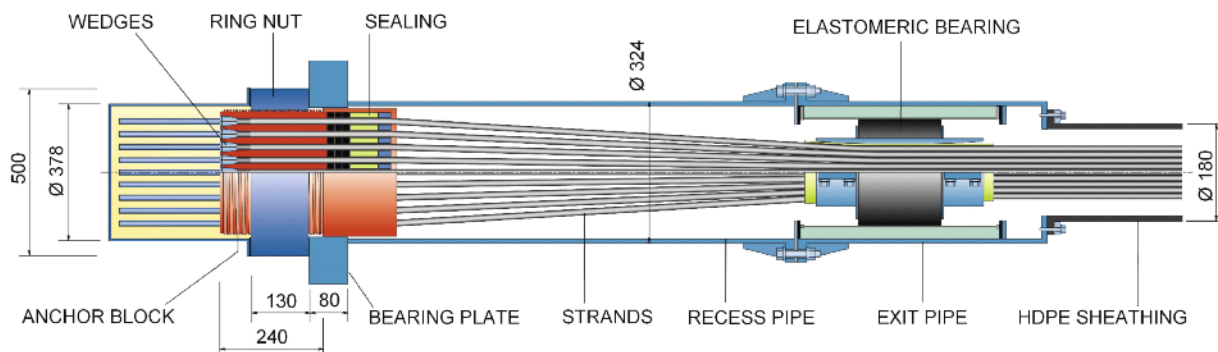
The strands are bundled approx. 2 m away from the

anchorages. The elastomeric bearings serve to reduce the bending moments in the anchorage zone and have dampening effects as well.

### 2.2. Approval Situation and Tests

The first-time use of parallel strand bundles in Germany required so-called individual approval by the construction supervisory board. The German Institute of Construction Engineering in Berlin (DIBt) was ordered to initiate the approval procedure for individual cases. An expert committee determined the approval criteria according to [1] for the stay cable system. In detail, these cover in particular:

- Single strand fatigue and tensile tests
- Stay cable systems tests on the scale of 1:1 under fatigue and tensile load
- Leak tightness test on the anchorage
- Replacement tests of individual strands under full service load



**Figure 2.**  
**DYNA Grip® Anchorage Type DG-P37**

- Installation and stressing of the stay cables
- Verification and/or prevention of cable vibrations
- Quality assurance of materials and installation
- Measurements
- Structural monitoring

### 2.2.1. Fatigue and tensile testing on stay cables and individual strands

The fib-guideline demands of the strand itself the fatigue strength of 300 N/mm<sup>2</sup> under the upper stress of 0.45 GUTS and 2 million load cycles. The wedge-anchored individual strand then had to endure at least the fatigue strength of 250 N/mm<sup>2</sup>, in order to reliably achieve the strength of 200 N/mm<sup>2</sup> required by the stay cable system. Special wedges fulfil the dynamic requirements.



**Figure 3.**  
Test Set-up for the Fatigue and Tensile Test

On three stay cables with 37 strands 0.62", St 1860 the qualification tests required according to [1] were carried out. Fig. 3 shows the test set-up at the Technical University Munich. Attention is drawn to the inclined position of both anchorages by 0.6° that were used for the first time in such tests. The test results are summarized in Table 1.

Only in one test a failure of one single wire occurred (permissible are 6 per test) indicated by an acoustic sensor during the fatigue test. The efficiency was between 0.925 and 0.947 AUTS; the tests were stopped for technical test reasons after the required values had been reached. The actual breaking load is higher. The required elongations of 1.5% under maximum loading were exceeded.

### 2.2.2. Leak tightness test

The purpose of the leak tightness test is to verify the adequate sealing of the stay cable system between the free length and the anchorage to avoid the ingress of water into the anchorage zone.

The test specimen consisted of a DYWIDAG DYNA Grip® stay cable type DG-P-37 with two stressing anchorages. It was mounted in an about 5 m high test rig (Fig. 4) which was filled up with dyed water to a water level of 3,0 m above the sealing of the lower anchorage.

The specimen was subjected to 10 load cycles between the stress levels of 45% and 20% GUTS and finally left under a load corresponding to 30% GUTS.

Subsequently, the test specimen was subjected to a series of 8 cycles of temperature variation from 20°C to 60°C and imposed 4 × 250 cycles of stay cable rotations of ±1.4°. The rotation was applied by a lateral movement of the stay anchorage at the top of the specimen.

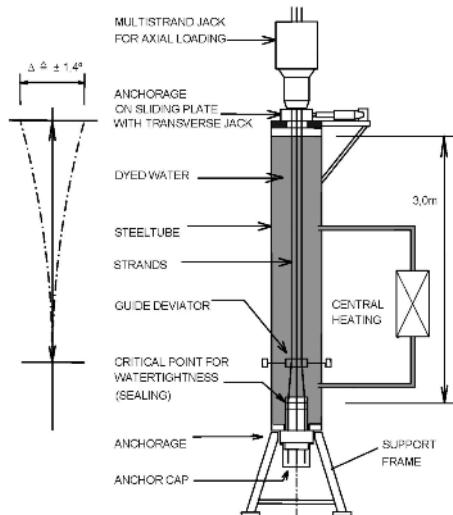
### 2.2.3. Exchange of individual strands

This test was performed to verify the exchange of individual strands after a tensile test. After reaching the ultimate load, the load was decreased to 30%

**Table 1.**  
Test results of tensile and fatigue testing at DYNA-Grip® system type DG-P37

Test No.	Wire fractures during fatigue	Measured maximum force [kN]	Efficiency GUTS ≥ 95%	Efficiency AUTS ≥ 92%	Elongation at max force ≥ 1,5%	Maximum elongation
1	0	9928	96.2%	92.6%	1.54%	1.59%
2	1	9915	96.0%	92.5%	1.53%	1.92%
3	0	10154	98.4%	94.7%	1.76%	1.87%





**Figure 4.**  
Test Set-up of the Leak Tightness Test

GUTS. Subsequently, the strand was de-tensioned using a single jack and both anchoring wedges were removed. A new strand was coupled onto the strand to be exchanged using a coupler whose outer diameter corresponds to the strand diameter. The old strand could easily be pulled out of the bundle while the new strand was inserted at the same time. The new strand was pre-stressed following the activation of the sealing. The leak tightness of the anchorage system was verified in a vacuum test.

### 2.3. Cable Installation

The pipe segments of the external sheathing were butt-welded together to their entire length lying on the bridge deck and afterwards lifted up into an inclined position. The strands were inserted using winches and individually stressed using the CON-TEN-method.



**Figure 5.**  
CON-TEN-Method

The patented CON-TEN-method (Fig. 5) uses two hydraulically connected single jacks ensuring that the strand to be pre-stressed is tensioned automatically up to the same load as the strand pre-stressed previously. The load in the pre-stressed strands decreases due to the steadily increasing structural deformation. Correct tensioning of the first strand ensures that in the last strand – and thus in all previous strands – the required load is achieved at the end of the stressing operation.

### 2.4. Quality Management

Basically a QA-system according to EN DIN ISO 9001:2000 was observed [2]. For all relevant materials an internal and external control was required according to EN 10204:2004 [3].

Regarding the strand, special attention was paid to corrosion protection, i.e. to the requirements of the

zinc coating according to [1] and pr EN 10337 [4], as well as to wax and PE-sheathing according to [1], and XPA 35-037 [5]. In addition, micro sections were taken in order to determine the evenness of the zinc coating thickness during production. Various steps were documented in manuals, such as for example:

- Production and material testing of the strands as well as of the cable components
- Assembly and installation instructions for the cables including pre-stressing instructions
- Measurement programme for the bridge gradients and subsequent vibration monitoring
- Maintenance programme.

Of course qualified and experienced personnel were available at the building site.

### 3. INTERNAL AND EXTERNAL PRE-STRESSING SYSTEMS

#### 3.1. European Harmonisation

In the past few years evaluation methods have been harmonised in Europe. There were a lot of national standards (e. g. British, DIN) and guidelines for testing provisions post-tensioning systems had to be subjected to. Some of these specifications were very detailed as a result of local experience. Some countries adapted and adopted specifications for the acceptance of PT systems running in other countries; others did not have any acceptance criteria for PT systems. The net result was that the systems available on the market were not easily comparable internationally because of the differing testing provisions they have been subjected to. This often created situations where post-tensioning systems have not been compared equally in terms of cost, because the performance, durability and level of safety of competing systems have been on completely different levels. What has been created with the CE marking and the European Technical Approval according to ETAG 013 [6] for post-tensioning kits is an international passport; the most up-to-date method to compare like-with-like, from which it is clear what specification the products fulfil, ensuring that all ETA systems provide the same minimum level of durability and safety. CE marked post-tensioning system installed by certified and responsible Post-tensioning Specialist Companies provide the highest level of quality and ensures an increasing safety for the owners of the structures.

#### 3.2. Post-tensioning Kits

Today's generations of stressing systems are meanwhile technically sophisticated products that have lost much of their "ductility" as a result of the stricter requirement profile. In addition to proofing their functionality, decisive importance is now assigned to the implementation into practice on construction sites by the manufacturers of the systems and their users. Strict compliance with the requirements for processing set out in the approvals is of overriding importance for the quality of stressing systems. This is also deemed necessary at the European level, with a CEN workshop [7] dealing with execution problems regarding the use of stressing systems on construction sites.

Post-tensioning kits comprise all elements that make up the complete tendon, which shall be placed on the market by a post-tensioning specialist company, who shall take the full responsibility for all components. As a matter of fact a comprehensive testing of these tendons was necessary.

##### 3.2.1. Static Tensile Tests

During a static tensile test, a complete tendon, including connection details from the anchor to the duct, is stressed by means of system complying stressing equipment to levels of 20%, 40%, 60% and 80% of the characteristic ultimate tensile strength of a tendon (UTS). The load of 80% is then maintained for duration of maximum two hours, subsequently released up to 20%, after which a tendon is stressed by means of an external testing machine to failure.

The key acceptance criteria are that no failure shall occur on the anchorage components, deformations, strains within the anchorage elements have to stabilize at constant load of 80% and an efficiency of at least 95% of the actual ultimate tensile strength of the tendon has to be achieved.

##### 3.2.2. Load Transfer Test

During the test (Fig.6) the anchorage components, including relevant reinforcement and concrete with the desired dimensions for a particular concrete strength, are subjected to 10 load cycles between 12% and 80% UTS, before the complete assembly is loaded to failure.

The key acceptance criteria is the stabilisation of any concrete cracking during the ten load cycles, a maximum crack width of 0.15 mm at the lower load and 0.25 mm at the upper load during the ten load cycles and finally and efficiency of at least 110% UTS of the particular tendon size.



**Figure 6.**  
**Load Transfer Test Set-up**

### 3.2.3. Fatigue Tests

The test specimen comprises all anchorage components as well as connection details to the duct. The deviation components (connection from the anchorage to the duct) are kept at a fixed distance from the anchorage to duplicate the actual deviation and the relative movements of the tensile elements with respect to the anchorage and duct. The actual fatigue test is performed with a stress range of 80 N/mm<sup>2</sup>.

The acceptance criteria are to pass 2 million load cycles without fatigue failure in the anchorage components and not more than 5% of the tensile element cross section shall be lost. Fatigue testing of post-tensioning systems is a new requirement in many parts of the world and requires particular care in detailing the components and construction site conforming transition point from the anchorage to the duct.

## 4. CONCLUSION

The Ziegelgraben Bridge is a good example for an implementation of the new recommendations to specify clear requirements for the tendon supplier regarding tests, material and quality and to simultaneously establish an interface to the planning engineer. All this was completed under permanent consideration of economic efficiency and durability.

The new recommendations proved themselves usable as a basis for future national recommendations.

The DYNA-Grip® Stay Cable System, which was used as a first application for German jobsites, fulfils all requirements demanded by the fib-Recommendations.

Objective of the new European Technical Approval is, amongst others, to ensure the “ductile” behaviour of the stressing system in extreme borderline situations. To this end, such firm requirements, acceptance criteria and test methods were developed that clearly go beyond those of national approvals as far as their extent is concerned. In addition, tests on the friction coefficient, deflection as well as the feasibility and reliability of the installation of all stressing systems are required, unless evidenced by experience values. On the top of this, there is additional evidence on optional utilisation categories and innovative systems [8].

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