Inspection and maintenance of post-tensioned tendons

Inspection and Maintenance of Post-Tensioned Tendons

Inspection et entretien des câbles de précontrainte

Inspektion und Unterhaltung von Vorspannkabeln

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SUMMARY
The paper discusses the inspection and maintenance of post-tensioned tendons in existing and future prestressed concrete structures. It includes brief presentations of current post-tensioning techniques with internal / external and bonded / unbonded tendons as well as the possibilities of non-destructive and destructive inspection.

RÉSUMÉ
L'exposé traite de l'inspection et de l'entretien des câbles de précontrainte dans des structures existantes ou futures. Les différents systèmes de précontrainte avec câbles intérieurs ou extérieurs sont brièvement décrits, qu'il s'agisse de précontrainte injectée ou sans adhérence. En outre, les possibilités d'investigation par le biais de tests non destructifs et à la ruine sont mentionnées.

ZUSAMMENFASSUNG
Der Beitrag handelt von der Inspektion und der Unterhaltung von Spannkabeln in heutigen und zukünftigen Spannbetontragwerken. Er schliesst kurze Erläuterungen zu den existierenden Spannverfahren mit internen bzw. externen Spanngliedern, sowie mit Spanngliedern mit und ohne Verbund ein. Ausserdem werden die zerstörungsfreien und zerstörenden Untersuchungsmethoden erwähnt.

1. INTRODUCTION

The first applications of the prestressing technology in modern times are now about 50 years old and most of them are still in service.

After 1945 prestressed concrete gained general acceptance very rapidly as it proved to be an ideal technique for rebuilding the infrastructure of post-war Europe. Later on prestressing was successfully introduced on the other continents.

Due to its inherent economical and technical advantages prestressing found applications in almost all fields of civil engineering structures such as:

- Bridges (spans ranging from 20 m to over 450 m)
- Buildings (slabs, beams, etc.)
- Circular Structures (reservoirs, silos, pressure tunnels, safety containments)
- Geotechnical Structures (foundations, ground slabs, anchored walls for excavations and numerous applications of prestressed ground anchors).

It is no exaggeration to say that prestressed concrete has revolutionized the civil engineering world. To illustrate this, it can be mentioned that today in many countries over 60 % of all existing bridges (related to the bridge deck area) have been built with this technique. At the same time considerable savings in money in the order of 10 to 20 % could be achieved by using prestressed concrete over other materials.

For many years engineers believed that concrete is virtually maintenance-free. Because of this, the design for maintenance was neglected. This is, however, on the verge to be changed. A comparatively small but nevertheless growing number of prestressed concrete structures show signs of minor or major destress.

The reasons for these unsatisfactory behaviours are the same as for other structural materials and can be summarized as follows:

- Design: Errors in planning, analysis, detailing.
- Execution: Unsatisfactory technology, human inadequacy.
- Service: Change of service conditions, e.g. environmental impacts (de-icing salts, etc.), increase in traffic loads.

It was Rüsch who rightly pointed out the inherent "system reserve" and the "cleverness" of reinforced and prestressed concrete structures. This on the other hand can also be a disadvantage because it takes a long time to recognize deficencies and to introduce the required improvements into future practice [1].

In this situation it is essential to follow two paths. We must continue to implement effective inspection and maintenance programs and if needed properly repair and strengthen our structures. At the same time, it is necessary to learn from errors for the design, execution and maintenance of future structures.

In the following, this paper will only deal with the inspection and maintenance of post-tensioning tendons.

2. PAST AND CURRENT POST-TENSIONING TECHNIQUES

Even if we concentrate only on post-tensioning and leave out other techniques, such as pre-tensioning and wire winding, we are still faced with a multitude of different prestressing steels and systems.

For the sake of completeness the definition of post-tensioned tendons is repeated here. A pt tendon consists in principle of four elements: prestressing steel as tensile member, mechanical anchorages, duct providing the void in the hardened concrete for the prestressing steel to move during stressing, filler material for the remaining void inside duct and anchorages (cement grout, grease, wax). The prestressing steel is stressed after sufficient hardening of the structural concrete and fixed in the anchorages. The filler material protects the steel against corrosion.

Especially in the beginning, engineers have been extremely innovative in creating pt systems. In the course of the years more than 100 different systems appeared on the market of which many, however, had a rather short life.

In addition some variations can be noticed throughout the years within an established pt system with regard to applied materials and field procedures.

Looking only at the main stream of current pt technology, we can first distinguish between internal and external tendons (tendons either inside the concrete or outside the concrete only connected at the anchorages and possibly also at deviation points). The bulk of applications has doubtless been with internal tendons.

After having been used in the initial phase of prestressed concrete (e.g. Dischinger Bridge at Aue, Saxony, GDR built 1936/37 [2]), external tendons however have recently seen a certain revival [3] with applications primarily in the USA (e.g. Long Key and Seven Mile Bridges in the Florida Keys designed by Figg & Muller), in France (after 1980 under the auspices of SETRA many bridges have been designed and built) and in the UK (Exe and Exminster Viaducts designed by Freemann, Fox & Partners).

Another important distinction must be made between bonded and unbonded tendons. Bonded tendons are those which are cement grouted after finishing the stressing operation.

The purpose of cement grout is two-fold; it provides sufficient bond between the prestressing steel and the surrounding concrete and protects the steel against corrosion.

The prestressing steel of unbonded tendons remains free to move along the tendon axis. It is only fixed to the concrete at the anchorages or couplers. The ducts can either consist of ordinary corrugated steel ducts or plastic sheathing (polyethylene or polypropylene either smooth or corrugated). As filler material suitable greases or waxes are normally used.

Practically all possible combinations of the above mentioned techniques are in existence and if properly designed and executed they perform as intended.

3. INSPECTION AND MAINTENANCE TODAY

In the civil engineering world the need for regular inspection and maintenance of concrete structures is generally accepted. There exist national or international standards indicating inspection intervals depending on criteria such as type of structure and environment [4].

Even if the principle is introduced, we can note in practice the full range between no tendon inspection at all which is by far the normal case and thorough, regular inspection for special structures only. For the latter the nuclear industry can be mentioned. From the early stages in the planning of prestressed concrete safety containments and pressure vessels, various regulatory bodies specified unbonded tendons. This concept allowed the monitoring of tendon forces, the possibility to adjust the tendon forces and to detension, remove and thoroughly inspect a particular tendon. For each US-containment in prestressed concrete a comprehensive and detailed surveillance program for pt tendons is in existence. For some earlier containments, inspection results over a period of more than 15 years are now documented.

Compared with other prestressing applications such an extensive surveillance program is exceptional. It was introduced because in the USA nuclear engineers were not familiar with this technique and therefore wanted to convince themselves of its reliability even more that pt tendons are absolutely vital for safety containments. It is interesting to note that later on, the French Electricité de France (EdF) for their 900- and 1300 MWe-Nuclear Power Station Program decided to use traditional cement grouted tendons because they are obviously more economical (lower initial costs and no expenditure for regular inspections) and because French engineers did not need to be convinced of their reliability.

It is a fact that except in some special applications as described above, pt tendons of prestressed concrete structures have not been designed for inspection. Everybody was convinced that the available concrete cover and the cement grout inside the ducts was sufficient for eternally protecting the steel against corrosion.

On the other hand pt tendons are a major element in assuring the required behaviour and safety of a structure both in service and ultimate conditions. In accepting this principle, also pt tendons must be inspected and maintained.

In order not to complicate the issue and to remain sufficiently practical, we concentrate in the following only on longitudinal pt tendons in bridge superstructures.

As the responsible engineer, we would like to know the actual status of the tendons. Let us assume that we have a ductile structure with more than one bonded tendon. In such a case the inspection engineer would primarily look for signs of destress or deteriorations such as unusual cracking, excessive deformations, wet or soaked areas, signs of rust, etc. In the presence of such defects and especially if the structure in question has been left unattended for many years, more thorough investigations are needed. We would like to know whether the prestressing steel has already been impaired by any form of corrosion.

What are the inspection methods theoretically available today? We can distinguish between non-destructive and destructive methods. For obvious reasons the client prefers non-destructive methods. Their essential disadvantage is that, if at all, they only show changes of certain properties in time.

We are not able to check directly the actual mechanical properties such as the ultimate tensile strength, but we measure some auxiliary value which is hopefully related to what we want to know. Methods in this category are gammagraphy, ultrasonic testing and potential measurements. Without going into detail, it must be mentioned, however, that these methods have unfortunately so many limitations, that they can only be recommended for special cases. Let us hope that in the future, researchers will come up with suitable non-destructive methods.

In order to apply destructive methods reasonably, it is advisable to look for potential weaknesses such as tendon high points, tendon couplers, construction joints, etc. First the tendon must be located inside the concrete. Then a hole is drilled carefully. The drilling must be stopped automatically when touching the tendon duct. In case the investigated area is not filled with cement grout (e.g. because of inadequate grouting procedure during execution) it is possible to visually inspect the prestressing steel with the help of an endoscope. The area can also be photographed.

Should corrosion be detected, it is generally up to the specialist to judge the situation and recommend measures. As a minimum requirement such detected voids must be properly filled with grout. If necessary, larger openings must be made and maybe even steel samples have to be cut out for testing the degree of deterioration in the laboratory.

Depending on the outcome of these investigations, proper maintenance, repair or strengthening measures can be decided. It is obvious, that the inspection methods available today are rather cumbersome. They are furthermore not entirely satisfactory, as they give us only results at some locations and not continuously over an entire structure.

4. OUTLOOK

In my personal view I see two main options for improvement. Also in this outlook I restrict myself to pt bridges. The reasoning can however be applied accordingly to other types of structures.

The first option is to retain the traditional technique of internal, bonded tendons. We primarily have to learn from past mistakes such as insufficient concrete cover, substandard concrete quality with regard to durability (carbonation, etc), incomplete duct injection with cement grout (e.g. voids at high points) and non-effective or even missing bridge deck insulation (in presence of aggressivity such as de-icing salts).

Furthermore quality assurance systems can help us to achieve the goal for better structures. The construction industry must profit from the good experiences of other industries. In particular any serious prestressing firm should have introduced by now an adequate quality assurance system [5].

All these measures and strategies will improve the quality of future structures. The principle that structures should be regularly inspected will still be retained. We will therefore still look for a method to qualitatively and quantitatively determine any harmful change of the entire pt tendon invisibly buried in the concrete. To my knowledge no method is available at present. It is known that specialists are currently working at it. The ideal solution would certainly be to measure the response of the tendon, longitudinally from one anchorage point to the other, to a physical impulse. Based on the result of a zero-measurement, any subsequent change could be detected. As a minimum requirement for the validity of method, the location of the actual damage should be given sufficiently precise and maybe also its nature.

The second option is to expand the application of external tendons. As mentioned in Chapter 2, the use of external tendons for bridges is increasing. In the context of inspection and maintenance of pt tendons the concept to arrange the tendons outside the concrete offers positive aspects. The "glassy" tendon inspectable at any stage seems theoretically possible. Due to several restrictions this is not true in its full extent; what is left however, is still considerable:
- the tendon force can be monitored
- the tendon force can be adjusted by restressing or detensioning
- the protective envelope of the tendon (steel or plastic tube) can be inspected and maintained without too much difficulties
- the tendon can be replaced.

Past and current designs do not fully utilize the potential possibilities that external tendons offer. More efforts are needed in this respect. It goes without saying that remarks made for the first option regarding the need for quality assurance, etc. are likewise valid.

In concluding, it is necessary to say that the involved parties in the design and construction process for prestressed concrete structures should realize the possibilities for improvement by introducing into new design ways to allow proper inspection and maintenance of pt tendons.

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