Contribution of the EMPA to the development of prestress technology

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Introduction

It can be shown that over the past few years, there has been a certain shift of emphasis in the development of prestress technology. This can be seen in the types of projects that the EMPA has carried out for various sections of the industry. Several years ago a large number of tests on prestress concrete members were made. These included beam tests concerning voids in the web [1] and tests concerning concrete hinges for a Gerber beam bridge. More recently the tests have been mainly centred around the *testing of large cables and their anchorages for their behavior under dynamic loading and also extreme temperature conditions*. These problems are not specifically for prestressed construction, but for all those structural systems where large forces must be taken up by cables e.g. guyed net structures or inclined cable bridges. It is not surprising then that the EMPA has also been active in this field of research. In the following it is intended to show several examples of these developments in research.

Testing rigs

In 1969 at the EMPA a testing rig was developed which for the *first time* allowed *fatigue tests with loading amplitudes of up to 2,5 MN and maximum loads of up to 6,7 MN*. A detailed description of this arrangement is given in [2]. The fatigue behavior of the Hi-Am (High-Amplitude) anchorage system for parallel strand cables and also entwined strand cables was able to be realistically tested with this testing rig. The Hi-Am anchorage system was used successfully for the *Rhein bridge Mannheim-Ludwigshafen* and for the *roof of the Olympic sports stadium* in *Munich* [3, 4, 5].

Apart from these fatigue tests, *failure tests* were carried out on the *anchorage heads*. These were made to test the *effects of aging* and *chemical decomposition on the epoxy cement used in the anchorage system*. An arrangement to change the force direction was also necessary. With the help of this arrangement the failure tests were carried out with the existing 20 MN presse. There was also a heating system present which was able to heat the anchorage heads up to a temperature of 115 °C.

An extension to the fatigue loading arrangement was made so that also the edge *cables of the Olympic tent roof construction* were able to be tested for fatigue. These cables passed over a *saddle with a small radius of curvature*. These tests aimed to find a cable with the greatest possible stiffness that could still be bent relatively easily. A suitable extension to the existing arrangement was made in order to meet this demand [2].

Apart from the already mentioned tests, a section of the necessary investigations were carried out on the existing testing equipment at the EMPA. As a result the first entwined cable to obtain permission for usage in Germany was a Swiss product. For this testing other innovations were also introduced. The most important of these were the *intermediate anchorages* [6].

Time dependent dynamic tests at low temperatures were carried out on a prestress cable of 139 single wires, each of 6 mm diameter. Only a small load variation ($n = 670$) was required. The minimum load was $P_u = 4{,}95$ MN and the maximum load was 5,65 MN. Thus the use of the customary rapid pulsators (frequency = 4,2 Hz) for producing the forces had to be overlooked. The establishing of the load limits with these machines is quite difficult. Ten to fifteen minutes elapse before the required force amplitude and the average force can be exactly obtained. These pulsators generate five hundred load changes in only two minutes. The time is hardly sufficient to establish the load limits. So it was necessary to find another machine which could generate the required force limits with a frequency of 0,5 Hz. The *Hydropacer* was found suitable. Apart from this a cooling system had to be installed around the upper anchorage head and also the cable itself. This was achieved in collaboration with the client and help from a specialist firm. The control, measurement and necessary corrections, to the temperature during the tests were made by the EMPA.

Quite *distinct fatigue problems* occur for *large steel cables* at the *saddle of the pylon for an inclined cable bridge*. Together with the force variation there exist internal stresses due to the cable curvature and also local pressures. The local pressures originate from the location of the cables with respect to one another. A testing arrangement was built at the EMPA to approximate as closely as possible the actual working conditions of this kind of structure. This is briefly described here [7].

The testing rig consists of two anchor blocks which are anchored to the mounting floor of the EMPA. Between these is placed the pylon saddle with variable radius. This saddle is set upon several loading press cylinders, which serve to provide the necessary cable forces. A number of these cylinders are combined to form a group and are connected to a nitrogen-filled accumulator, which is held under pressure by a spring controlled manometer. The job of this first group is to hold the minimum load quantity constant throughout the dynamic tests. The second group of test cylinders are connected to a pulsator and provide the required force amplitude.

The force measurement in the cable and the controlling of the test loads is achieved with special dynamic force measuring gauges which are fixed onto both sides of the cable. With these the cable force was able to be found to within ± 5 kN. Pin-joints were built in between the fixed steel plates of the anchorage blocks. This overcame the possible introduction of flexural actions into the cable during the dynamic tests and guaranteed a clean introduction of the tensile force into the cable.

In addition to the force measurement in the cable it is possible to *simultaneously measure the slip of the cable at each anchor block*. Also the elongation due to the tensile force in the cable can be measured on the free cable length. This is made over a 2 m length and allows the determination of the deformation modulus for the total cable. For this measurement there are as well as mechanical procedures also electrical procedures available. These allow the strain measurement to be made and observed during the dynamic testing without interruption of the actual test. Additionally the *diameter changes* can be determined.

The production of *local bearing pressures* occurs over a distribution plate which is fastened to the cable with bolts. The actual pressure the force produced in each bolt was found with a measuring gauge connected in between. Tests have showed that the variations in the local bearing pressure are smaller than 5%.

The testing rig is as shown in figure 1. It can be adapted relatively easily for cables with less sag. A load increase is also possible by adding a fourth loading press cylinder. The various possibilities should be examined for each particular situation. However the testing arrangement is limited by the available raising height of 15 mm for a single press cylinder connected to a pulsator. Also the local bearing can only go to 2,45 kN/m before the addition of extra bolts is necessary.

A second testing rig which also serves for the testing of cab les that change direction over a saddle is also available. This arrangement allows forces up to $P_o \cong 6{,}0$ MN for loading amplitudes of approximately $\Delta P \cong 1{,}0$ MN. The cable length is naturally shorter than that for the arrangement shown in figure 1, amounting to about $l = 6000$ mm.

Further projects

From the many tests made on various bridges by the EMPA, two particular cases are worth mentioning here. The tests made were not, because of the *particular constructions of the bridges*, like the usual bridge tests. An *underpass at Eiken* in Canton Aargau [8] and a *partially prestressed lightweight concrete bridge* at *Schaffhausen* [9] are the two bridges concerned.

The first mentioned project concerned a *skew multi-cell box-section bridge without transverse beams*. To investigate the behavior of this rather uncommon construction, load tests were carried out on a single box-section girder before the bridge deck joints were closed. Further tests were also carried out on the finished bridge. The results obtained are presented [8].

The *dynamic behavior* of the lightweight concrete bridge was the area of main interest for those tests. The bridge was *dynamically loaded at various points*. The tests produced interesting results and so increased the information available concerning the *dynamic behavior of lightweight concrete structures with partial prestressing*. These tests compliment the tests currently being carried out by the EMPA which are concerned with the dynamic behavior of bridge structures under traffic loading.

A further test in this area of research consisted of the *comparison of theoretically and experimentally measured dynamic behavior brought about by a truck*. This test was made on the *bridge over the Limmat at Neuenhof* and is extensively reported in [10].

In conclusion it should be mentioned that the EMPA would like to assist on the basis of their experience in the work concerned with the writing of the relevant Codes from the Swiss Engineers' and Architects' Association (SIA) [11]. These codes should contain sensible and responsible clauses which however do not cause difficulties for future technical developments.

Outlook

Today the requirement of prestress systems and cables for inclined cable bridges are many and highly varied. Clients are always requiring more from tests carried out to show that particular systems meet the various performance requirements. These tests are aimed to be as close as possible to the actual situation in loading and also boundary conditions. Often quite considerable difficulties arise when it is attempted to meet the actual boundary conditions. Up till now the EMPA has made an effort to do justice to these projects and in doing so to provide a useful contribution to the further development and improvement of the prestress systems. The testing facilities which are now available enable a very flexible testing laboratory to be formed. In the future it will be fully endeavoured to promote technical developments in this area. This will be done through continued activity with experimental investigations. Also research work and work concerned with the design codes will be supported.

References (see German part of this Article)

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Die Rolle des Schweizerischen Ingenieur- und Architektenvereins (SIA) in der Entwicklung des Spannbetons

Von **Aldo Cogliatti**, Zürich

Bindeglied zwischen Behörden, Hochschulen und Baupraxis

Ein nachhaltiger, positiver Einfluss eines Berufsvereins auf die Entwicklung der Konstruktionen ist nicht allein vom Wissen und Können der Ingenieure abhängig, sondern in hohem Masse auch von der politischen Struktur und den Traditionen eines Landes.

Unser liberales Staatswesen mit seiner *betont föderalistischen, direkten Demokratie* überträgt Regierung und Verwaltung ein Minimum an Aufgaben. Das war früher noch ausgeprägter, gilt aber, im Vergleich zu allen andern Ländern, auch heute noch. Stark und lebendig blieb deshalb der Einfluss der ganzen Bevölkerung auf die Politik, und weite Kreise nehmen Anteil an den Problemen der Volkswirtschaft.

Gewiss sind auch *Nachteile* mit dieser Tradition verknüpft, z.B. die Möglichkeit, dringende Entscheidungen erheblich, ja sogar mutwillig zu verzögern. Die *Vorteile*, bewiesen durch unsere andauernde Gesamtstabilität, überwiegen aber bei weitem. Sie gehören zu den wesentlichen Voraussetzungen zur Steigerung der Lebensqualität für alle.

So ist es traditionell auch in der Schweiz selbstverständlich, dass *privatrechtlich organisierte Stellen* anspruchsvolle und permanente Aufgaben im Bereich der *angewandten Forschung* übernehmen. Der SIA betreut seit mehr als 100 Jahren das schweizerische *Normenwerk* für die Baukonstruktionen und die Zusammenarbeit im Bauwesen. In dieser Rolle verstehen wir uns als eigentliches Bindeglied zwischen Behörden, Hochschulen und Bauwirtschaft.

Verantwortliche Instanz für die Normen der Baukonstruktionen

Ergebnisse der Grundlagen-Forschung – seien sie strukturtheoretischer oder materialtechnischer Natur – sind selten direkt nutzbar für den Planungs- und Bauprozess. Ihre Verarbeitung zu konzentrierten Richtlinien, zu eigentlichen «Regeln der Baukunst», stellt immer höhere Anforderungen. Das Normenwerk à jour zu halten erfordert heute eine permanente, aber flexible Organisation.

Die wesentliche Arbeit leisten unsere Fachleute in den entsprechenden *Kommissionen*. Dabei werden nur die Basisentwürfe honoriert, nicht aber die ganze Kommissionsarbeit. 10 Prozent aller Vereinsmitglieder, über 800 Ingenieure und Architekten, arbeiten in irgendeiner Form und Funktion vollständig ehrenamtlich mit. Die Zusammenarbeit von Professoren, Chefbeamten, Consultants und Unternehmern wird als wertvoll und von vielen als eine wesentliche Bereicherung, nicht zuletzt in menschlicher Hinsicht, empfunden.

Wir unterscheiden *verschiedene Stufen der Verbindlichkeit im technischen Normenwerk: Empfehlungen, Richtlinien* und *eigentliche Normen*. Ein besonderes Verfahren regelt die Wege der Vernehmlassung und Genehmigung. Etliche Normen sind von Behörden oder Bundesbahnen allgemein verbindlich erklärt worden. Dies sind insbesondere die Vorschriften für die Tragwerksicherheiten und alle Ingenieurkonstruktionen. Sie sind immer Grundlage der entsprechenden Verträge. Im Prozess dienen sie dem Richter, den Stand der Bautechnik zu interpretieren.

Während sich *Kommissionen* spezifisch mit *Erarbeitung und Erneuerung* des Normenwerks befassen, ist die *administrative* Begleitung Sache des *Generalsekretariates* und die *Genehmigung* Angelegenheit der *Zentralinstanzen* des Vereins. Die *Verbreitung in die Baupraxis* als Teil der *Weiterbildung* hingegen ist Sache der *Fachgruppen* (vergl. Organisationsschema). In Tagungen oder Kursen werden die neuen Texte vorgestellt und diskutiert. Im internationalen Bereich sorgen Delegationen unserer Fachgruppen für den Austausch der Erfahrungen. Die FBH (Fachgruppe für Brücken- und Hochbau) vertritt traditionsgemäss die Bauingenieure an den internationalen Kongressen der Konstrukteure, insbesondere auch für den Spannbeton.

Der Spannbeton im Normenwerk

Der SIA nimmt also über das Normenwerk sehr direkt Einfluss auf die Entwicklung der Bauwerke und trägt auch eine entsprechende Verantwortung. Wir können das nur deshalb mit gutem Gewissen, weil der Konsens der Normen von den führenden Fachleuten selbst erarbeitet und bei Behörden, Schulen und Wirtschaft breit abgestützt ist.

Das gilt insbesondere auch für den Spannbeton. Die zuständigen Dozenten der ETH, die Ressortchefs der Ma-