Outstanding structures other than bridges and buildings

Autor(en): **Delisle, Jean-Pierre**

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- Exécution du forage.
- Mise en place et scellement du tirant.
- Mise en tension du tirant.

Les tirants précontraints sont permanents et doivent pouvoir être contrôlés, retendus ou complètement relâchés en tout temps. En plus, ils doivent pouvoir s'adapter à des mouvements du terrain de quelques centimètres sans que la protection contre la corrosion des tirants soit endommagée. Les tirants BBRV type GK contrôlable de 145 tonnes utilisés au nombre de 308 pour le Lot Bachmattli et les tirants VSL type TMD 5–12 de 125, 90 et 72 tonnes utilisés au nombre de 151 pour le Lot Delli répondaient aux exigences imposées.

Maître de l'ouvrage: *Owner*	Baudepartement des Kantons Obwalden
Ingénieur: *Engineer*	Werffeli et Winkler, Sarnen
Entreprises: *Contractors*	Bürgi AG, Alpnach *Lot Bachmattli* Stahlton AG, Zürich Stump Bohr AG, Zürich *Lot Delli* Spannbeton AG, Lyssach SIF-Groutbor, Lausanne

Outstanding structures other than bridges and buildings

Prestressing is a construction principle that finds interesting applications outside the field of bridges and buildings. We are going to rapidly describe some applications made in Switzerland between 1974 and 1978, applications that can be qualified as outstanding either by their originality or by the high level of the prestressing forces involved.

The first application concerns the *restoration and the consolidation* of the Jesuit church in Lucerne. The following two applications refer to *hydraulic constructions:* the pressure gallery of the Grimsel-Oberaar hydro-electric scheme and the Fieschertal water intake. The last ones are connected with *foundations* and *excavations:* the concrete in situ diaphragm wall, Rentenanstalt, Tessinerplatz, Zurich, the prestressed anchors, Taillepied 8, Lutry and the embankment stabilization on the RN8 near Alpnachstad.

Consolidation of the Jesuit Church in Lucerne

The towers of the Jesuit church in Lucerne (figure 1) were built in 1893, 230 years after the construction of the church itself, without the then existing foundations being strengthened. The subsoil consists, to a depth of 20 metres, of silt and clay lake deposits. Differential subsidences of 20 to 30 cm occured between the choir of the church and the towers. In 1966 the towers were 124 mm out of plumb and transversal cracks had developed in the roof of the church. Long term measurements showed that the church was continuing to lengthen, at the top of the arch of the roof, by 1.5 mm a year.

To stop the process that was likely to lead to the complete destruction of the building, the engineer in charge of the consolidation of the church used the prestressing technique. Figure 2 shows schematically the consolidation principle. The apse, with its massive 2 metre walls, forms an "anchor block" for the three levels of cables A, B and C which exert horizontal forces, of 70 tonnes and 50 tonnes, designed to join the towers to the rest of the building and to modify the pressure distribution exerted by the towers on the foundations. Cables D, E and F hold the two towers and the front wall of the building together.

Figures 3a and 3b show the arrangement of the cables A, B and C. Cable A is placed in the floor of a lateral gallery which has been rebuilt in reinforced concrete and acts as stiffening and bracing for the longitudinal walls of the aisle. As cable A reaches the tower it is divided into two 35 tonne cables to avoid obstructing a passage. Cable C, situated in the aisle above the walls, is continued in the apse by a cable placed 1.8 metres lower so as to be able to bear against a sufficient mass of the apse wall. Around the apse the cables are placed in grooves cut in the 2 metre thick walls.

The cables were first stressed to 30% of their nominal force. This delicate operation was followed by numerous observers situated at the critical points and whose job it was to pass on all their observations by radio. A diminution of the opening of the cracks was measured. After the stressing and a sufficient lapse of time for the creep effects to diminish, the shortening of the aisle was of 12 mm. The final 70% of the prestressing force was applied 3 months later after the transversal cracks in the arch had been filled in with a very plastic mortar composed of sand, cement and lime.

Pressure galleries of the Oberaar-Grimsel hydro-electric scheme

Three sections of the pressure gallery of the Oberaar-Grimsel hydro-electric scheme had to be armoured: the first two, under an inner pressure of 7.5 bars, due to an insufficient rock coverage (section A of figure 4a "Druckstollen Aare") and the third one, under an inner pressure of 15 bars, due to the close proximity of an access gallery and a cable gallery (section B of figure 4a "Unterwasserstollen Grimsel").

A solution in prestressed concrete with cables stressed from the inside of the gallery, was prefered to steel plating because, as well as being 10% cheaper, it presented, compared to steel plating, the following advantages:

- absence of the danger of buckling of the armour when the galleries are not under pressure;
- maintenance is greatly reduced as there is no need for a protection against corrosion;
- reduced section of the access gallery.

The typical cross-sections A and B are represented in figures 4b and 4c. The concrete lining is prestressed by cables describing a full circle and stressed from the inside by means of intermediate anchors placed in 20 cm deep niches. The section of the gallery is free and the hydraulic profile is undisturbed.

In the case of the A sections the cables are placed every 24 cm; they are 110 tonne VSL ZU 6-6 cables composed of six 0.6″ strands, greased and each placed in a polyethylene sheath. To compensate for the secondary moments introduced by the slight eccentricity of the cables in the region of the niches, and to avoid over weakening the cross-section the niches are staggered. For the A sections four different positions for the niches in the lower half of the gallery are sufficient, whereas for section B six positions spread around the entire section were necessary. Figures 5 to 7 show different stages of construction.

Fieschertal water intake

In the case of the Fieschertal hydro-electric scheme the water intake had to be built between two rock faces at an altitude of about 1640 m close to the Fiesch glacier.

As the subsoil on which the water intake dam rests is unstable due to the presence of ice lenses (fig. 8a), it was decided to design the structure as a simply-supported beam resting at both ends on supports cut out of the rock. The left bank end is anchored in the rock by means of 10 BBRV 247 tonnes (54 ⌀ 7) ties of an average length of 26 m. So as to be able to support itself as well as a certain weight of ice in case of a readvancing of the glacier, the structure has been prestressed by 113 BBRV 240 tonnes (52 ⌀ 7) cables of about 33 m long (fig. 8a–10).

Prestressed concrete wall Rentenanstalt, Tessinerplatz, Zurich

The protection of excavations by means of concrete diaphragm walls anchored by prestressed ties is a construction procedure that enables an easy excavation due to the absence of internal shoring. To carry out the foundations of a building, with four stories below ground level, in an area of heavy traffic near the Enge railway station in Zurich (fig. 11), the engineer used a prestressed diaphragm wall. In this case prestressing has the following advantages:

a) A single row of prestressed ties placed at the top of the wall is sufficient as prestressing enables larger "free" span. As a result, excavation can proceed continuously without interruption for the installation and stressing of intermediate rows of anchors. In addition if such anchors had been necessary they would have had to be installed at levels below that of the water-table, in other words under pressure, with all the difficulties that entails.

b) Prestressing forces the wall against the earth. As a result ground movement in the areas surrounding the excavation is reduced to a minimum.

c) The reduced weight of the reinforcement cages simplifies the lifting and placing operations.

The topmost 4 or 5 metres of subsoil are made up of various soft strata that cover layers of clay, sand and silty gravel. At and below the level of the planned raft foundations these layers are compact. The water-table level is between 2.50 and 3.50 metres below ground level.

The diaphragm wall is 80 cm thick. Its total length measured along the perimeter of the building is 213 metres. It is made up of 4 corner elements and 61 linear elements varying in width between 2.75 and 3.70 metres, and in depth between 19.00 and 22.00 metres.

All the elements except the corner ones are vertically prestressed using BBRV prestressing cables with a capacity of between 240 and 250 tonnes per cable (nominal value corresponding to 70% of the breaking stress). Two cables were used in each element to form a pair of "U" s (fig. 11b) resulting in 4 stressing locations at the top of each element.

The cable profile was calculated to counteract the bending moments produced in the wall by earth, water and surcharge pressures. The position of the cables is fixed by horizontal stirrup cable supports. In addition, all the elements are reinforced by conventional bar reinforcement.

The topmost part of the wall, concreted under mud, was removed until sound concrete was reached. A layer of 20 to 30 cm of contaminated or poor quality concrete usually had to be broken out. A capping beam of conventional reinforced concrete, covering the anchor heads and joining the wall elements together, was then concreted.

The wall is anchored in the ground by means of prestressed ties of the Stump Bohr Duplex type. These are placed at between 2.50 and 4.00 m below ground level and are stressed to provide forces of 50 to 70 tonnes per linear metre of wall. The length of the ground anchors varies between 20 and 30 metres and they are inclined at an angle of 20° to 35° to the horizontal. These anchors are relaxed and dismantled at the term of the construction.

Vertical permanent ground anchors, of the Stump Bohr Duplex type, were also used to resist hydrostatic uplift in those areas were there was insufficient weight of construction. A total of 64 such anchors were used.

The reinforcement cages, consisting of conventional and prestressed reinforcement, of the first elements, were assembled on site. During stocking and handling of the cables and assembly of the cages, numerous sheaths were damaged and had to be repaired. Subsequently it was found preferable to prefabricate the cages off the site and to fetch them as they were needed. All the cages were carefully inspected by a representative of the engineer. No mud or concrete blockage occured in the cables.

The flexibility of the cages caused some problems. A 25 cm diameter wooden post was placed in the middle of the cages to give them a certain stiffness. After the cage had been placed in the trench, the post was removed to be replaced by a concreting tube. The concrete had a cement content of 350 kg PC/m^3; the maximum aggregate size was 20 mm and the 28 day cube crushing strength was 30 N/mm^2.

"U" shaped reinforcement rods were placed around the looped cables at the bottom of the cages to avoid a cracking of the wall due to the splitting forces introduced by the cables. No cracks in the concrete or abnormal movements of the cables were observed during stressing.

During the entire construction period, the movements of the walls were followed by theodolite surveys and deflection measures at four points. Anchor forces were also measured in the two ties adjacent to the points of deflection measurement (see figure 11a).

Prestressed anchors, Taillepied 8, Lutry

To re-establish the slope stability after the excavation of the foundations of a building below the Simplon railway line, it was necessary to stabilize the slope by means of prestressed anchors exerting an average total force of 105 tonnes per linear metre of slope (see figure 14).

This construction is interesting due to the high level of the prestressing forces involved. It is indeed unusual to execute 245 tonnes (force corresponding to 70% of the rupture stress) permanent anchors in loose terrain.

The anchors consist of 11 ⌀ 12 mm rods for the 145 tonnes anchors and 20 ⌀ 12 mm rods for the 245 tonnes ones; they are equiped with a central tube à manchettes enabling repeated injections of the anchoring area. The diametres of the ties, at the time of placing, are 110 mm and 120 mm for the 145 tonnes and 245 tonnes anchors respectively. Three to four injections were necessary to attain the required resistance in the anchoring area. A special high initial strength cement was used for these injections so as to shorten the waiting periods between different injections and excavation stages.

Even with the dimensions of the anchor plates (2.50 × 4.00 m for the first row of anchors and 2.50 × 2.80 m for the third, see figure 15) settlement of a few centimetres occurred during stressing. The cables had to be restressed numerous times to compensate for the losses caused by settlement and creep of the terrain behind the anchor blocks.

Stabilization of the hillside embankment of the Alpnachstad-Delli, section of the RN8

On the section of N8 national highway between Alpnachstad and Delli (Obwald), the disposition of three thoroughfares parallel to the lake side, caused a problem. These three were the new highway, the existing single-line Brünig CFF railway line, and the old local road. As the available space between the lake and the slope was insufficient at places, and as the gradient of the slope was to steep to think of filling in the lake, it was decided to cut into the hillside. Landslides occured soon after the beginning of the work and various stretches of the hillside had to be stabilized.

To guarantee the stability of the slope, at an angle of 60°, a discontinuous wall system was used. The latter was made up of plate elements pressed against the terrain by means of prestressed ties anchored deep in the stable rock (see figure 16 and 17). This method was the most favourable from the economic point of view and was also the most satisfactory aesthetically.

Consolidation work in the zones of potential landslide was carried out in stages, from top to bottom. Excavation was continued only after the ties of the row of elements immediately above had been stressed. The work was carried out as follows (fig. 18 and 19):

- Hand excavation of the plate element areas.
- Site concreting, in vertical formwork, of the reinforced concrete plate elements (5.00 m × 5.00 m or 5.00 m × 6.50 m depending on the lots) with trumpets and niches for the ties.
- Tipping up of the elements against the bank.
- Filling up of the space between the ground and the element with a filtering no-fines concrete. The reinforced concrete element acts as a form.
- Execution of the boring.
- Placing and anchoring of the ties.
- Stressing of the ties.

The prestressed ties are permanent and must be so formed that they can be checked, restressed, completely relaxed, at all times. In addition, they must be able to adapt themselves to movements of the terrain of a few centimetres, without damaging the corrosion protection of the ties. On the Bachmattli lot, 208 BBRV 145 tonnes ties of the verifiable GK type were used, whereas the Delli lot needed 151 VSL 125, 90 and 72 tonnes ties of the TMD 5–12 type. All these ties satisfied the requirements.

Adresse de l'auteur: Prof. *J.-P. Delisle,* Laboratoire des Matériaux Pierreux de l'Ecole Polytechnique Fédérale de Lausanne, Ch. de Bellerive 32, 1007 Lausanne.