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Prestressed concrete in building construction

In the following article the usage of prestressing in building construction in Switzerland over the past few years is illustrated. Although due to the recession, there are very few striking new developments currently being introduced, several matters are worth mentioning.

Generally only *partial prestressing* is being used for building construction. Full prestressing is used only in exeptional cases. For partial prestressing of flexural members the design is initially carried out for the load case «dead load only». The member is designed so as to have between 10 and 20 kg/cm^2 maximum tensile stress for an uncracked cross-section. Conventional reinforcement is added for the load case «total load», i.e. «dead load and live load». The check for allowable stresses for this load case, in principle a check of the crack width present, is made on a cracked cross-section based upon the principles of reinforced concrete design (design for bending and axial force = prestress force). In addition to this – as for full prestress – a check on the ultimate strength of the section is to be carried out.

Prestressed flat slabs with and without bond

Prestressing has found itself a firm place in flat slab construction. Prestressed flat slabs are particularly economical for spans between around 6 and 12 m. Also only small slab deflections occur for concrete of low strength under dead load only. Thus only a short time is required before formwork can be removed.

Three different prestress steel arrangements can be distinguished (Fig. 1):

a) Distributed cables in both directions in middle and column strips,

b) Distributed cables in one direction, in the other direction cables concentrated in the column strip,

c) Cables in both directions concentrated in the column strips (column strip prestressing).

In Switzerland the most commonly used arrangement ist the *column strip prestressing c)*. With this method the transverse components of the cable forces are only acting upwards. The downward acting transverse components are directly taken by the columns. Therefore of the three arrangements mentioned the column strip prestressing produces the smallest punching shear stresses. Square slab bays must be thus reinforced similarly to a slab continuous and supported on all sides in order to obtain the optimal effect from the prestress compression force.

Administration building of Hoffmann-La Roche & Co. AG, Basel

The administration building of Hoffmann-La Roche & Co. AG, Basel, (Figs. 2 and 3) has a ground plan area of 132 × 59 m and in the basement floors, a column grid of 8.1 × 8.1 m. The four office floors above have a dead load of 200 kg/m^2 and a live load of 500 kg/m^2. For these floors only half the number of columns needed in the basement are required. The diagonal prestressing arrangement produces a span of 11.45 m. The slab thickness is 38 cm. The four cables in each column strip were stressed to 60% four days after concreting. This was the minimum time before formwork could be removed. The total prestress force $V = 145$ t was achieved after twelve days. This made possible a rapid rate of progress and also minimised formwork material. Within six months 24800 m^2 area of slab had been poured. At the construction joints the cables were fitted with movable anchors and rigid coupling devices. This allowed the prestressing of the slab segments with relatively small friction losses and also guaranteed continuity of the prestressing. The prestress steel quantity was 6.5 kg/m^2 of slab and the reinforcement quantity 30 kg/m^2. The columns were solid steel with a diameter of 25 cm (top floors) and 35 cm (bottom floors). A steel bearing plate 70 × 70 cm was used at the column head.

Underground garage of the Canton Hospital, Basel

Column strip prestressing was used also for the flat slabs, measuring approximately 150 × 50 m, of the underground garage of the Canton Hospital at Basel (Figs. 4, 5, 6). The intermediate slabs were 30 cm thick for a column grid of 7.50 × 8.50 m. The top slab was 1 m thick. The unterground shelter is to serve as a civilian shelter in times of war and is built for an external pressure of 3 atm. Therefore the top slab had to be designed for the unusually high total load of 35 t/m^2. In each column strip four cables were placed each with $V = 117$ t. The slab was poured in four segments, each 27.5 × 47 m. The two cables visible in the foreground of figure 5 serve to compress the construction joints between the slab segments. The prestress steel quantity for this slab comes to 13.5 kg/m^2, the quantity of reinforcement to 70 kg/m^2. The slab is supported on a steel bearing plate with a diameter of 100 cm at the column head.

An original construction method was developed for the construction of this underground garage. The garage was not, as is usually the case, constructed in an open cut excavation from bottom to top, but with a so-called *«sinking slab procedure»* from the top to the bottom. The slabs were poured and then prestressed one on top of the other at ground level and also at the top level of the already placed 15 m long columns. After this stage was completed the excavation beneath the slabs was begun and the single slabs successively sunk with 24 prestress jacks.

Educational Centre Zofingen

Recently in Switzerland *small prestress steel members without bond* have been used to prestress flat slabs. The following advantages over conventional cables can be listed:

- larger eccentricity of the prestress steel because the sheath diameter is only 18 mm particularly relevant for thin slabs,
- faster building progress through simple laying of the lighter prestress steel and the use of small hand jacks for prestressing,
- able to prestress to 100% in a shorter time as there are smaller anchorage bearing stresses on the concrete,
- no grout injection.

At the Educational Centre Zofingen the flat slabs (Figs. 7, 8) had to be designed for a dead load of 130 kg/m^2 and a live load of 300 kg/m^2. The slab thickness was 28 cm for a column grid of 10 × 7.5 m. In each column strip up to 18 0.6″ single strands (without bond) with $V = 18$ t were placed. The quantity of prestress steel came to 4.5 kg/m^2 and the reinforcement quantity was 15.6 kg/m^2. The concrete columns with diameter = 50 cm could be constructed without a local strengthening at their heads.

Transfer girder constructions

Again and again prestressed concrete has proved to be an excellent method for the solution of unusual constructional problems. This is especially true with regards to transfer girder constructions.

School building with indoor swimming pool, Aadorf

The school building for senior classes in Aadorf has a circular ground plan with a diameter of about 39 m (Figs. 9, 10). The two top floors are used for teaching purposes. Below these floors is an indoor pool. No internal columns were possible in the pool area. The top floor load bearing walls, formed in a star shaped pattern, were thus designed to form a very stiff supporting structure. From these walls the slab over the pool, measuring 1100 m^2, is supported. Eight prestressed concrete hanging columns are situated at the intermediate floor, providing the architect with a large amount of freedom for the arrangement of the community areas, like the library, handwork areas, special rooms etc. accomodated on this floor.

In the load bearing walls four prestressed cables with $V = 220$ t were arranged and taken through the floor slab around the rectangular opening for the stairway. So that the anchorages could be accomodated at the edge of the roof slab, local strengthening in the slab had to be made. The hanging columns were each prestressed with one cable, $V = 145$ t.

Administration building Giesshübel for the Swiss Credit Union

In the administration building Giesshübel for the Swiss Credit Union in Zurich a 25 × 25 m × 74 cm thick prestressed waffle slab was constructed (Figs. 11 and 12). The slab was designed for a live load of 500 kg/m² and in addition for three suspended point loads of 183 t, 125 t and 72 t. The slab is supported on single columns at the third points along the edges and is continuous at two adjacent edges. The prestress steel in the centre ribs is 8 or 9 cables with $V = 190$ t. The quantity of prestress steel is thus high, amounting to 12.8 kg/m² of slab. The reinforcement quantity is 61 kg/m².

Hall constructions

St. Jakob Sport Hall, Basel

The suspended shell of St. Jakob Sport Hall has a span of 90 m, a vertical sag of 6 m and a thickness of only 7.5 cm (Figs. 13 and 14). It is constructed out of lightweight concrete with a specific weight of 1.7 t to 1.75 t/m³. The self weight of the roof including water-proofing, 3 cm cork and a sheet of fibre glass paper, came to only 150 kg/m². The main steel consisted of 0.5″ single strands with sheaths which were prestressed and injected with grout. These had a spacing of 30 cm and were situated between two special reinforcement meshes, each with a weight of 6.3 kg/m². The shell was built on a sidewards shifting scaffold in strips of 10 m width. These strips were prestressed after three days to take their self weight loading. The final prestressing was carried out only after all the strips had been concreted. The inclined columns for taking up the support reactions of the suspended shell were prestressed for dead load in such a way as to obtain load balancing. This meant that the only bending moments and shear forces resulting came from the live load and, in particular, from the snow and wind loads.

Rapid goods hall of the Swiss National Railway, Zurich-Altstetten

The rapid goods hall of the Swiss National Railway, Zurich-Altstetten (Figs. 15, 16 and 17) has a construction consisting of large continous frames with a main span of 60 m and, transverse to the frames, 23 m long × 3 m wide hyperboloid (HP) shells. Between every two HP shells are skylights. The in-situ concrete frames consist of a hollow box cross-section with a width of 2.2 m, a depth of 2.5 to 3.3 m, web thickness of 20 cm, bottom flange thickness of 20 cm and top flange thickness of 40 cm. Along the bottom edge are continuous support nibs for the HP shells and also for the rainwater drainage pipes. The relatively deep and torsionally very rigid main beams are partially prestressed with four cables, $V = 240$ t and six cables with $V = 185$ t, i.e. with a total prestress force $V_{tot} = 2070$ t. The 3 m wide and 7 cm thick HP shells are pretensioned with 16 directly bonded wires of 7 mm diameter. The support brackets for the HP shells were prefabricated and fixed to the nibs of the main beams. The finished hall presented a most impressive internal view.

Large containing structures

Clinker silos of the cement factory at Rekingen

Large containing structures are often prestressed with a winding procedure for the prestressing cable. The protection against corrosion of the prestressing steel is usually achieved with a layer of shotcrete. The procedure is relatively straight forward with liquid containing structures. These can be filled and will expand to a maximum before the shotcreting. However if the shotcrete is not placed when the maximum internal pressure is present, there exists the danger that the shotcrete layer will crack later because of additional deformations. Then protection against corrosion cannot be guaranteed.

For clinker silos the largest internal pressure together with the largest deformations occur during the emptying of the silo. The filled condition is therefore not particularly favourable for the winding procedure of the prestressing cable. At the cement factory Rekingen a conventional prestressing system was chosen for the two clinker silos using single cables (Fig. 18). This system has the advantage that the openings in the silo can be passed around and a normal corrosion protection achieved through the injection of mortar.

The 64 m high containers have an internal diameter of 34 m and a wall thickness of 38 cm. They are prestressed with 57 m long cables with $V = 141$ t (12 ⌀ 12.5 mm) running around half the perimeter. The vertical spacing of the cables, suited to the magnitude of the internal pressure increases from 28 cm at the bottom to 64 cm at the top. Mesh reinforcement is provided to the external and internal faces for shrinkage, temperature, wind and earthquake effects. Also the flexural edge disturbances are taken care of with jointless transition to simple strip footings with normal reinforcement. The average quantity per m² of the container wall is 25 kg prestress steel and 45 kg reinforcement including cable sheath and local anchorage reinforcement.

The silos were constructed with a slip-form procedure, giving a daily production of 4,5 to 5 m of container wall. The prestressing cables could be layed rationally and very rapidly by means of a «monorail» construction so that no delays in the slip-form procedure occurred.

Connection of precast segments through prestressing

Prestress techniques are being used more and more for the connecting of precast segments. Two examples are described in this report.

Multi-storey building core in the shopping centre Wallisellen

For the construction of the building complex for the Shopping Centre Wallisellen, measuring 1 000 000 m³, only an extremely short construction time was available. At first a steel structure was considered. However exacter studies pointed to a solution using *prefabricated concrete elements*. The building core was also prefabricated to save time and, to provide the necessary stability, was prestressed with vertical cables going down into the foundation slab.

The core of the approximately 75 m high 17 floor multi-storey building consisted of seven shafts partially separated by vertical joints (Figs. 19 and 20). Each shaft was formed from 51 to 57 hollow box prefabricated elements stacked on top of each other. Each element had the dimensions of 8×3×1.33 m with a wall thickness of 20 cm. Five shafts were prestressed to take up the horizontal forces coming from wind and earthquake loading. In each of these shafts two cables with $V = 145$ t were placed in three parts of about 20 m length and coupled to the already placed and from above prestressed segment below. The separation of the cable into parts was necessary in order to provide a sufficient stability during construction. After the assembly the cables were injected with grout.

Indoor swimming pool in Adliswil

As well as the new swimming pool building at Adliswil, the actual pool was totally prefabricated (dimensions: 25 m × 12.5 m × 2.0 m, see Figs. 21 and 22). The floor and wall elements of the pool were already clad with tiles in the prefabricating plant. These were placed exactly upon a separating surface made from building paper and plastic sheeting which allowed movement of the precast elements. They were then prestressed together with prestress bars of 12 mm diameter. The walls were thus horizontally prestressed and the floor slab prestressed longitudinally and transversely. This method has an extra advantage in that the shrinkage of the elements has already occurred to a large degree before the actual assembly of the elements. Thus any problems concerning the watertightness of the pool are avoided.

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