CONCRETE

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PLUS...

Innsbruck Ski Jump Tower, computers in design of concrete structures, news from ACIFC and much, much more.

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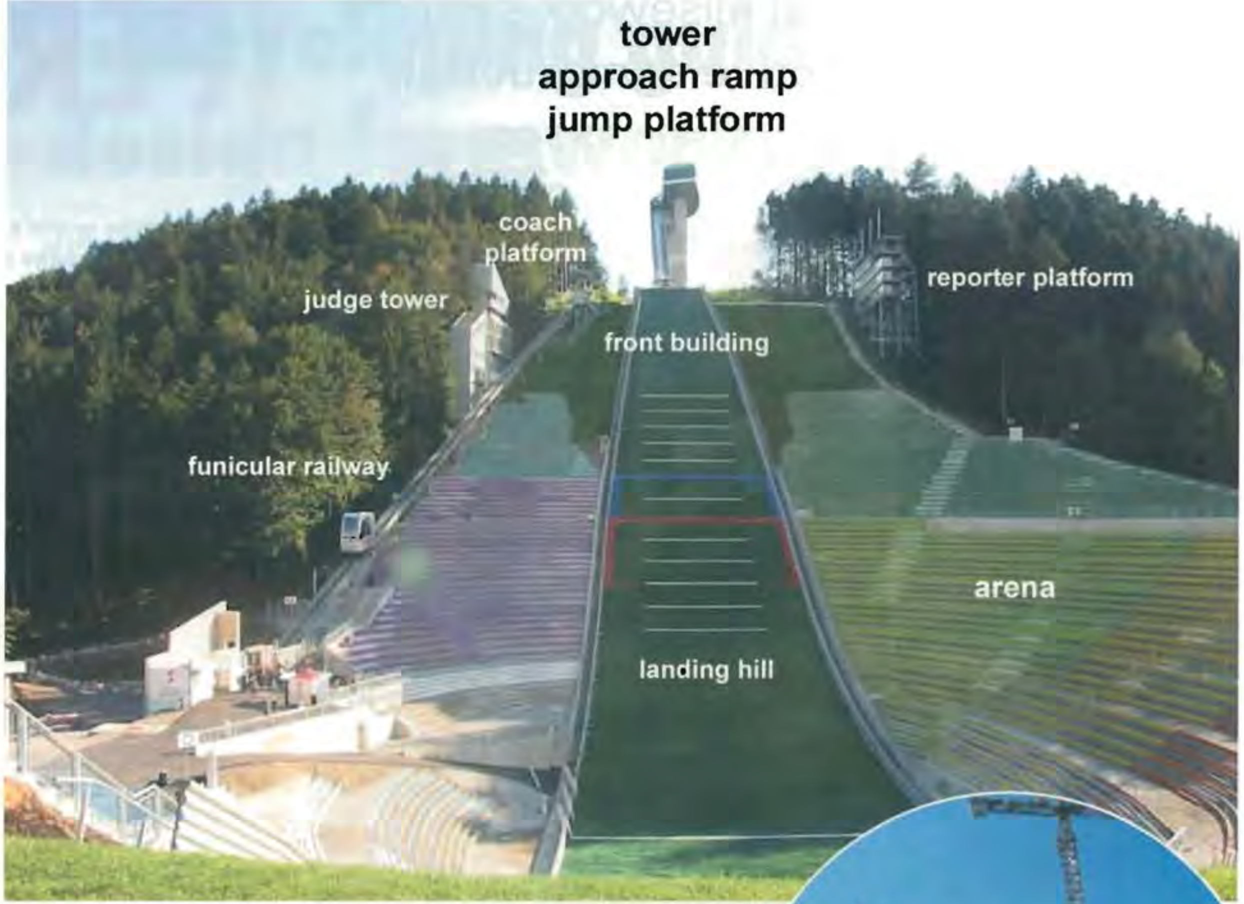

Figure 1: The full ski-jump project.
RIGHT: Figure 2: Tower and column-free approach ramp.

Innsbruck ski jump tower:

a triumph of mixed building technology

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The ski jump in Innsbruck, known for the famous annual New Year 'Four-ski-jump-tournament' has been replaced. The original tower, built for the 1976 Winter Olympics, was completely demolished, and a new landmark, similar to a lighthouse, erected on a small hill on the city limits. Architect Zaha Hadid, based in London, won the international architectural competition. The consulting engineers were Aste Konstruktion, who won the Austrian State Award for Consulting 2002. Construction took place according to a very strict timetable, being handed to the client in time for the event in January 2002. It was fully opened in September 2002, complete with the restaurant at the top (see Figure 1).

The project

Concrete was used in the following elements of the structure:

Tower

This is 48.5m above ground, and the top is 791m above sea level, making it 13.8m higher than the old tower. It was constructed from a concrete box with a section of 7×7m and wall thickness of 400mm. Local prestressing is used at the top, and a prestressed slender bearing cantilever used for the approach ramp. The entire structure was constructed using climbing formwork and fair-faced concrete. Concreting began in June 2001.

Tower top

This consists of three levels: a steel hollow-section space frame, prestressed docking brackets at the concrete tower, trapezoidal composite slabs, concrete cantilevers and a glass and metal sheet facade. Construction, including a restaurant for 80 guests, took place during Winter 2001–Spring 2002.

Take-off building and ski jump platform

The concrete abutment is designed to look like the knee of a ski jumper and is 24m in length. Approach ramp bridge supports are positioned 10m higher than on the earlier structure.

Front building

This is a three-storey concrete building with bent roof below the jump platform. It contains technical equipment, power

ABOVE: Figure 3: Lifting the second part of the approach ramp.
RIGHT: Figure 4: Distance triangles for the cable suspension.

generation equipment, common rooms and a storeroom.

Landing hill

This consists of concrete fixing and border bead or retaining wall, transverse ribs in a distance of 30m, underfloor transverse drainage, holding devices for the snow nets and plastic mats for the summer jumping, mat sprinkler system.

Approach ramp bridge

This is one of the main hybrid structural elements. The initial design for the approach ramp consisted of a continuous four-span girder with three piers, making it akin to the earlier structure. The final design does not have any intermediate support for 68.5m with an inclination of 35°. It was designed as a fish-bellied trough bridge with steel trusses and suspension (see Figure 2). The preloading leads to compression in the trough girder. The transverse distribution of the central preloading into the string trusses was solved by the end cross-girders, together with space tubes within the support areas.

In terms of cost, the concrete continuous girder and column-free steel trough bridge were quite similar. However, questions relating to the intermediate piers were decisive. Doubts remained concerning dynamic behaviour due to wind and seismic loadings. Investigations of oscillation frequency indicated that the three-bar system, consisting of two steel trusses and the centric suspension, provided sufficient stability. Furthermore, the catenary sag of the longitudinal section positively affected the equilibrium position. The architects were very co-operative, and the original slender four-span concrete girder was transformed to the actual free-spanning organic 'vertebrate'.

Constructional design calculations were undertaken by Aste Konstruktion, Innsbruck. The executive steel contractor, Pichler, made sure these concurred. Forces on the structure are the dead load, snow (350mm thick, resulting in a load of 9kN/m^2), wind, seismic and service loadings, such as the track preparation machine. Strict serviceability requirements had been prescribed and controlled by the International Ski Federation, due to the influence of small deviations on the jump flight parabola. The actual deflection difference between full load and dead load is 81mm, effectively corresponding to $L/1000$.

The bridge cross-section consists of rectangular hollow section trusses (construction between 1.15 and 1.80m), positioned horizontally up to approximately 4.5m. These trusses are finally covered by alloyed steel sheets and glass. The standard rectangular hollow section for the upper and lower flange measure 300×200×14.2mm. That of the filler beams is 180×180×12.5mm. Special attention had to be paid to the erection order of this steep bridge, which has a difference in altitude of 31.5m between the supports. The lower part of the trough was mounted on the ground from two string trusses. Each consisted of two sections, welded on site. The trough was crane-lifted on 24 November 2001 and positioned on the take-off building and temporary pier. This gave exactly the desired position for dead load.

After two weeks, the 40m long upper string truss near the concrete tower was lifted after pre-welding on the ground. This was threaded on the very slender pre-stressed concrete cantilever (1400×400mm) and constructed using the lower string truss (see Figure 3). The external string truss was constructed using the same approach. Within a day, all cross-girders were mounted on the string gir-

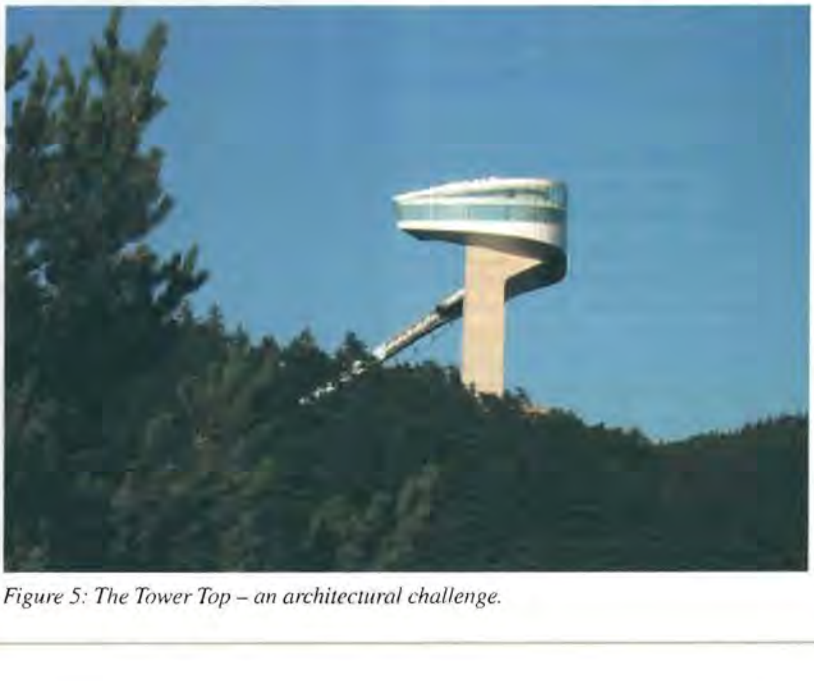

Figure 5: The Tower Top – an architectural challenge.

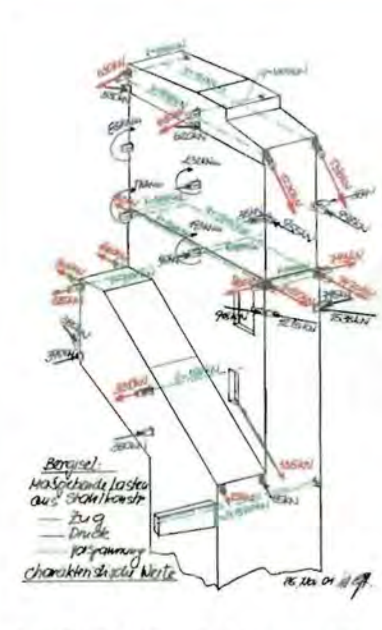

Figure 6: LEFT AND ABOVE – The docking station between the concrete tower and steel cage with prestressed bearing plates.

ders by bolted end-plate connections. The desired longitudinal section was adjusted, and the lower and upper string truss parts welded together near the temporary pier.

The mounting of the distance triangles for the cable suspension followed. These were temporarily braced against each other to withstand friction forces during prestressing. The five cable stays were threaded through the holes in the triangles, and the re-entrant steel profile decks with end anchoring deformations (see Figure 4) were placed between the 2m spacing cross-girders. The concrete topping had to wait until half of the prestressing (1000kN) was complete.

The structure loosened out of the temporary support as expected. Due to concreting the approach track, the fish-bellied girder again settled on the temporary pier and was lifted up for 15mm by the second half of the prestressing. The auxiliary pier was removed. The five prestressing cables are frictionless covered mono-strands with a design prestressing load of 400kN per strand. The approach ramp erection, including concreting, was completed in less than four weeks.

Tower top

The tower top is extraordinary, both architecturally and structurally. On top of the concrete section, there is a three-level steel cap with rescue access, restaurant and observation platform. At 250m above the city centre, there are fantastic views over Innsbruck and the surrounding mountains. The levels cantilever around the concrete core up to 11.5m. Together with the steel hollow section frames and diagonal suspension tubes anchoring back to the concrete core, there is a steel cage. The horizontal core stiffening is achieved using composite slabs at these three levels. The transparency and elegance of the facade is achieved by the elimination of diagonal bars within the front and huge glass elements in the facade (see Figure 5).

The docking forces between the steel cap and concrete core were crucial to the achievement of this hybrid structure, solved using special prestressed steel brackets (see Figure 6). These docking elements did not affect the climbing formwork. On the other hand, they provided sufficient welding length for introduction of the tension forces.

The positioning, adjustment and fixing of these pre-fabricated brackets was a considerable achievement. Each had a maximum weight of 550kg within the formwork. The strength development of concrete at low temperatures became significant, due to the altitude. The design calculations were performed according to Austrian standards and Eurocodes 3 and 4. The tower top weighs approximately 90 tonnes.

Conclusion

The new building is an excellent combination of architectural shape and structural design. The use of fair-faced concrete, steel and glass epitomise the architectural style of Zaha Hadid. Construction and erection were based on modern steel–concrete hybrid technology. The concrete core was achieved using climbing formwork, prestressed steel docking brackets were used for the steel frame cage on the tower top, a prestressed slender concrete cantilever was used as the upper support of the approach ramp. There is a three-level widely cantilevering steel frame cage on the top and an approach ramp in the form of an organic fish-bellied and suspended trough bridge.

The final task, the restaurant at the top of the structure, was finalised in Summer 2002. The summer jumping season in Innsbruck started with a sensational opening ceremony and a mat jump event on 14 September.

The 'lighthouse' of Innsbruck is a new landmark, a symbol for sports, youth and progress, showing concrete and steel working together in harmony (see Figure 7). ■

Figure 7: Full opening of the ski-jump in September 2002.