Central Station Dresden

Renovation of the platform halls

SSF Ingenieure

Renovation of the platform halls of the historic Central Station Dresden is a unique project because of the size of the new membrane roof which was assembled within the existing structure. The architect Lord Norman Foster designed the whole 30,000 m^2 roof surface of the entire platform halls to be covered with a PTFE-coated fibreglass skin and the existing steel truss to be renovated and reinforced.

One of the greatest engineering challenges for the team of designers from SSF/Buro Happold was presented by the loads of the new membrane roof and their insertion into the historic steel truss to transfer them to the foundations. Renewal of the hall roofs as well as the associated metal fibre was planned with the principle to preserve authentic elements and to renovate them. In the areas where original design elements were no longer present, modern solutions were chosen which harmonized with the character of the platform halls.

This resulted in an overall concept which respects and emphasizes the old structure and the history of the station but also integrates modern and innovative concepts and represents the development of railway. On November 14th, 2007 the team SSF Ingenieure/ Ingenieurbüro Happold in London was given the Structural Award for Infrastructure 2007 for renovation of the platform halls.

Description

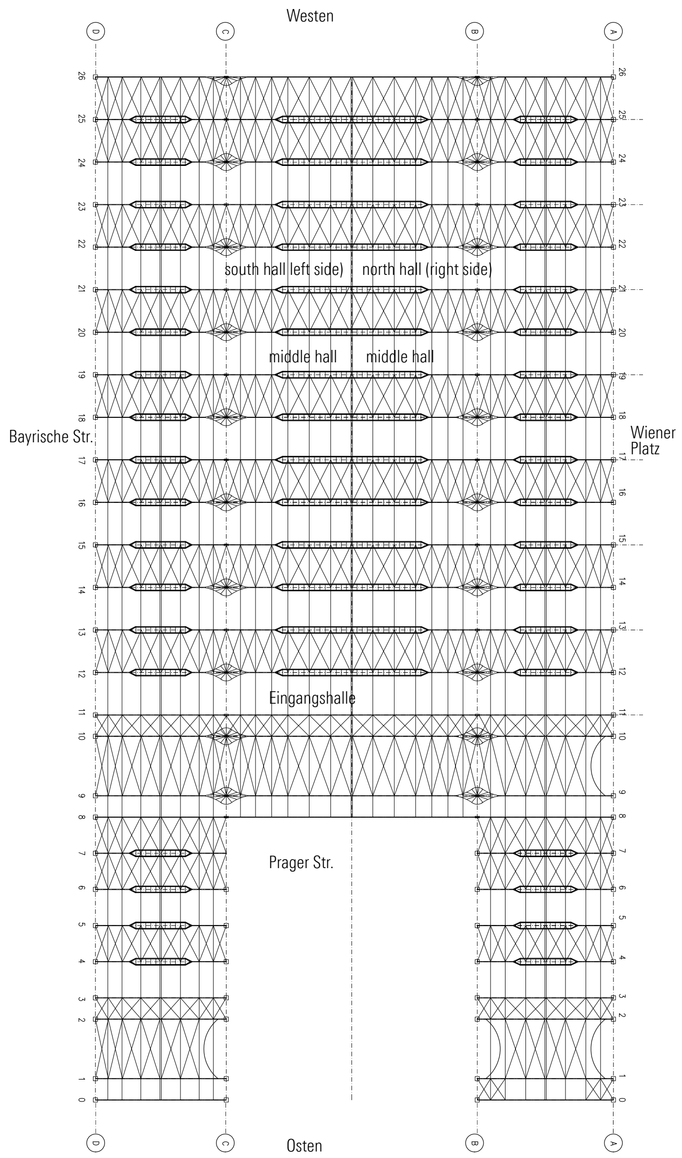
Dresden Central Station was built between 1892 and 1898 based on the design of architects Giese und Weidner and is, after Leipzig and Berlin, the third largest station in East Germany. Moreover, it is one of the most impressive train station buildings of the late 1900s in Europe.

The 240.5 m long and 121.75 m wide structure of Dresden Central Station consists of a solid station building to which are connected three platform halls: the north, middle and south halls. The middle hall designed as dead-end station is added in longitudinal direction at the front end of the west side and the two side halls, transit halls with elevated track, join the station building on the north and south side. Both side halls are approximately 32.0 meters long, the middle hall 60 meters wide and 35 meters high. The arches of the platform halls with mild steel infill are arranged in transverse direction at distances of 5.0 to 14.0 meters

picture credit: Ulrich Windoffer

main longitudinal portal, north view

roof plan



and in longitudinal direction in unison with the façade's design. At the ends, each hall is covered by glazed aprons as well as glazed, load-bearing exterior façades. From a vertical view, the structure is divided in three levels: basement, ground floor and the elevated tracks of the north and south hall at about 4.5 m above the ground floor.

Existing structure 1999

Basis of the design concept was a comprehensive assessment of the actual state of the platform halls. During extensive research in the archives of the German Railway Company DB AG and the City of Dresden, remaining as-built-documents were compiled, brought together and drawn up after site visits under symmetry conditions; then they were examined and revised in the context of structural inspection and regular assessment according to German Standard DIN/DS 803.

The results of the as-built research showed that except from the load-bearing structure only few elements of the old station – one of the last structures of Wilhelminism stile – still remained. During renovation works in the 1930s, the cast iron elements and typical historical tinplate ornaments were reduced in the sense of neo-realism. During air raids of the allied forces in the Second World War, the platform halls were heavily damaged and newly designed after the War. The covers of corrugated iron and the overhead glazing of the large skylights were replaced during post-war renovation by timber-lagging and cap-shaped dormers with lateral window walls.

Roof truss

The steel truss of the platform halls of Central Station Dresden was designed in its static basic concept of the original construction period as arch truss in order to absorb vertical roof loads from dead-weight of the steel, the timber, glass and tinplate covers as well as snow loads. The conversion from a solid roof cover to a membrane roof led to a reduction of the truss' dead-weight. On the other hand, due to spatial pre-stressing forces of the membrane, huge compressive stresses occur in the arch truss that are additionally augmented in the areas of the middle hall and the adjoining bow strings because of the formation of snow pouches due to the membrane roof's shape. The implementation of spatial-geometrical and static load-bearing requirements, with respect to static/structural conditions of the existing linear truss, necessitated the assembly of a geometrically and statically combining steel substructure as well as a profound modification of the old steel truss in order to distribute altered loads. The steel substructure of the membrane roof is thus divided into the primary structure of the old truss and the secondary spatial steel substructure of the membrane truss to be erected.

Membrane

The membrane roof consists of individual panels installed between the arch trusses, completely covering the whole roof surface in the final state. The width of the individual sections is about 10 meters at average and varies between 5 and 14 meters. The membrane was connected to steel pipes of the steel substructure in longitudinal and transversal direction of the arches. In the transitional areas between the middle and side halls, the membrane roof is shaped downwards at every second arch to form a conic low point. The result is a static reasonable bend in longitudinal direction of the hall and allows the arrangement of drainage openings. Near these low points, the membrane is laid along freely suspended cables – so called flying cables – from the middle hall to the side halls in order to support the aesthetically desired and statically logic bend in longitudinal direction. Contrary to the previous roof cover, the membrane sheet transmits

1 **view** of complex 1905
3 **construction stage** 10-m-membrane section

2 **interior view** of middle hall with north hall– inner façade
4 **construction stage** secondary truss with support arch– 14-m section

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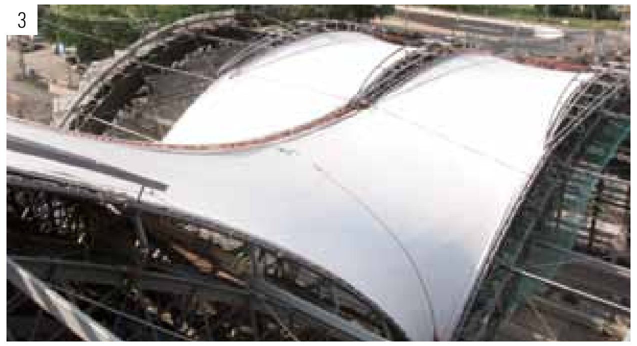

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picture credits : Ulrich Windoffer

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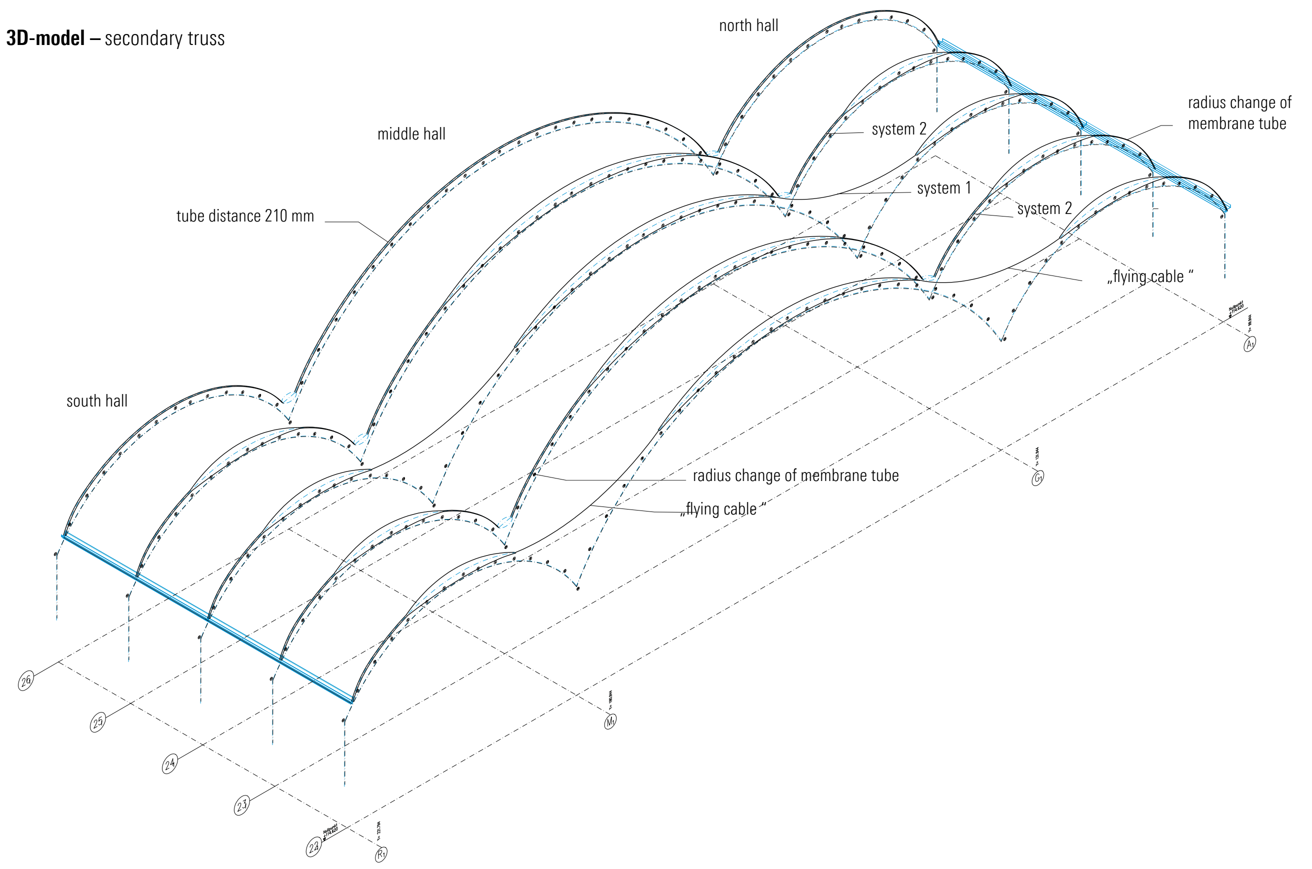
3D-model – secondary truss



middle hall arch with secondary truss

the loads by tensile forces oriented in the membrane plane to the steel structure. In case of symmetric loads and in the load case pre-stress of adjoining membrane sections, the horizontal components of tensile forces attacking from both sides compensate each other. When calculating asymmetric load cases of adjoining membrane sections, the resulting horizontal components are to be taken into account for load absorption by the old truss structure. To avoid over-loading of the old structure in case of failure of one membrane section, the individual arch trusses are joint at the upper chords by stabilizing cables. The fixed typical membrane details take into consideration the use of relatively simple and low-cost membrane clamps which do not allow re-tensioning or adjustment on site. Consequently, the membrane has to be cut very accurately and a mounting procedure has to be developed which corresponds to the concept of dead-length fit. In the design this aspect was respected by the consideration of membrane tensions and bearing behaviour under reduced pre-stress.

picture credits: Ulrich Windoffer

Membrane material

In addition to strength requirements, fire protection, exposure to diesel exhaust and other chemicals, cleaning necessities and self-cleaning effect of the material, a possibly high life-cycle and the comparison with reference projects for material choice were decisive. After examination of these material requirements in view of this particular use, a PTFE (polytetrafluoroethylene) coated fibreglass was chosen.

Form finding/computer calculations

From the concept to the visualization of detailed features, model building was essential throughout the project. Parallel to the physical model, a computer model was drawn up at a very early stage.

In the first stage of form finding, a balanced state within the membrane was established which considered stress states in warp and weft. The determination of membrane stiffness was based on previous experience of numerous other projects as well as the average values of completed tests. Identification of decisive membrane tensions allowed the definition of characteristics of the material to be used. By determining deformation it became visible if the membrane touches the underneath purlins in certain load cases and which membrane deformation was to be taken into account for design of the structural load-bearing structure. When dimensioning membrane roofs for reason of the exclusive tensile stress tolerances of the material, attention has to be given to the fact that pre-stress in combination with the applied loads increases or decreases but must not be reversed into compressive stress. The possibility of failure of individual membrane sections was also respected during these examinations.

left: membrane roof section with lenticular skylights
middle: construction stage station building with finished membrane roof
right: horizontal couplings secondary truss

Dimensioning
The membrane material was dimensioned with consideration of the reduction factor from influences resulting from durable loads, environment, temperature, clamp connections and a global safety factor regarding stability. These factors were confirmed by later material coefficient tests.

Approval procedure / singular case approval of membrane
Because the used membrane material including the membrane clamps is a non-regulated construction product, it was necessary to apply for a singular case approval at the building authority. Part of the application documents, in addition to design documents and approval design, were the material and constructional element test results.

Cutting patterns and compensation
After the form finding process and dimensioning, the next design step consisted of conceiving cutting patterns. A particular difficulty resided in translating the pre-stressed, spatially bend form of the final state in plane and un-stretched cutting patterns. As the material was tension-free during cutting, the later material stretch had to be taken into account; that means every individual cutting part has to be produced with reduction of the calculated elongation travel. The procedure of considering every material and structure specific relaxation process is called compensation.

Load-bearing structure / steel substructure
The steel substructure acts as adaptor for the spatial membrane geometry on the orthogonal existing arch truss and the load transmission of the membrane forces to the frame structure of the hall arches. To assure a high degree of prefabrication as well in membrane convectioning as in steel construction of the secondary truss, the geometry concept was implemented in two basic forms so that they could be implemented independently of the existing tolerances.

According to the membrane roof's geometry, the secondary truss follows the membrane's basic forms in transversal direction of the hall with the high and low points changing in longitudinal direction of the hall in the middle axis. Above the bow string vertex the membrane sheet opens lenticular to the system axes of the individual arch trusses. The opening is covered by glass skylights. According to both roof systems described above, the membrane system is laid at the high points along double-cables from the pipe ends of the middle hall's skylights to the pipe ends of the side halls' skylights. In the system of low points, the two membrane pipes are formed as double-pipes leading, in the middle and in the side halls, uniaxialy, radially bent from the front end of the skylight to the roof's low points in the middle axis. The pipe ends of the membrane are connected to the membrane by a spatial elliptically bent pipe ring to which the inlet funnels are joint.


steel construction lenticular skylight

At the longitudinal walls, the membrane is tensioned continuously linear against rectangular tubing. In the special case of the 14-m-long longitudinal portal section above the main entrances of the station, the rectangular tubing is executed radially to the portal arches. For horizontal stiffening of the arch section in transverse direction of the hall, an inclined round arch is assembled which is connected articulated to the external bowstring trusses of the adjoining bowstrings.

The static/structural design of the secondary truss as well as its connections to the old truss are realized under the principle of showing force flow from the steel substructure to the existing truss during bearing and loading and of designing the detailed formation with regard to modern fabrication and mounting conditions in such way that the steel constructional conditions correspond with the existing structure and harmonize with both trusses.

picture credits: Ulrich Windoffer


view of hall apron – west

Existing structure
The old load-bearing structure reaching over the whole length of the halls was divided into individual stiffened truss sections of two arches in the middle fields and three arches in the end fields. These arches were connected with each other by horizontal infill elements and stiffened in longitudinal direction. The purlins of the individual load-bearing fields are linked by stabilizing cables to transmit accidental horizontal loads in case of failure of one membrane field. To seize spatial force flows with regard to the given stiffness relations between spatial steel substructure and linear old load-bearing structure, it was necessary to determine


regular symmetry – membrane roof

internal forces at the entire spatial system. The membrane pipes of the steel substructure were in principle separated in the area of the bowstring vertexes to avoid a system coupling to the primary truss. Renovation and dimensioning of the primary truss as a result of determined internal forces, was carried out with the principle to maintain, analogous to the concept of the whole measure, the existing load-bearing structure with its filigree design and to replace only some constructional elements and bars for static/steel-constructional reasons due to their degree of damage. New elements were built on the basis of modern steel constructional production and storage conditions.

Façades

Maintenance of the façades was of great importance in the context of the whole measure. The pre-damages as well as, from a current point of view, the post-war improper renovation, required the complete replacement of the glass façades including the linked steel substructures and general renovation of the historic frame structures and the tinplate ornaments. New construction and renovation were realized profile- and system-compatible with modern structural adaptations of the steel construction to assure a high serviceability and no maintenance.

Construction execution

Construction schedule / interference with other projects

Before the award of contract, construction preparation by the planning team required the determination of several construction stages, mounting technology as well as the necessary makeshift constructions to assure feasibility of the whole concept as this project planned to maintain railway and passenger traffic with long-term advance notice of track block-offs but also interfered with other constructions running at the same time such as the demolition and rebuilding of the new north hall's elevated track as well as renovation of the station building.

The chosen basic technology included an approximately 40-m-long displaceable steel working scaffolding per platform hall which formed, above the column shoes of the existing truss, a working level to execute renovation, corrosion protection and mounting works and served at the same time as fall protection and separation of the construction from the station level. The chosen construction schedule planned execution of work in several stages in seven sections. In addition to the degree of difficulty that presented the measure, the implementation was complicated by the floods from 2002.

Steel renovation

An essential part of the construction was steel and corrosion protection renovation on the existing structure which had been carried out improperly or not at all because of missing resources or because of inappropriate post-war renovation. After preparation of the surface, the truss was examined for cracks during a visual inspection and the damage patterns and thickness measurements of the bar cross-sections were recorded. After evaluation of damage patterns and thickness measurements, static verifications of the existing structure were made on the basis of the determined remaining cross-section and the belonging renovation planning.

Completion

After completion of the construction in the third quarter of 2005, all makeshift constructions – including the temporary purlins, which were necessary until achievement of adhesion of both fix points at the hall ends – were removed and adhesion was created in interaction with the whole truss system of the membrane, the secondary truss and the existing truss.

interior view middle hall – 10-m regular section

picture credits: Ulrich Windoffer

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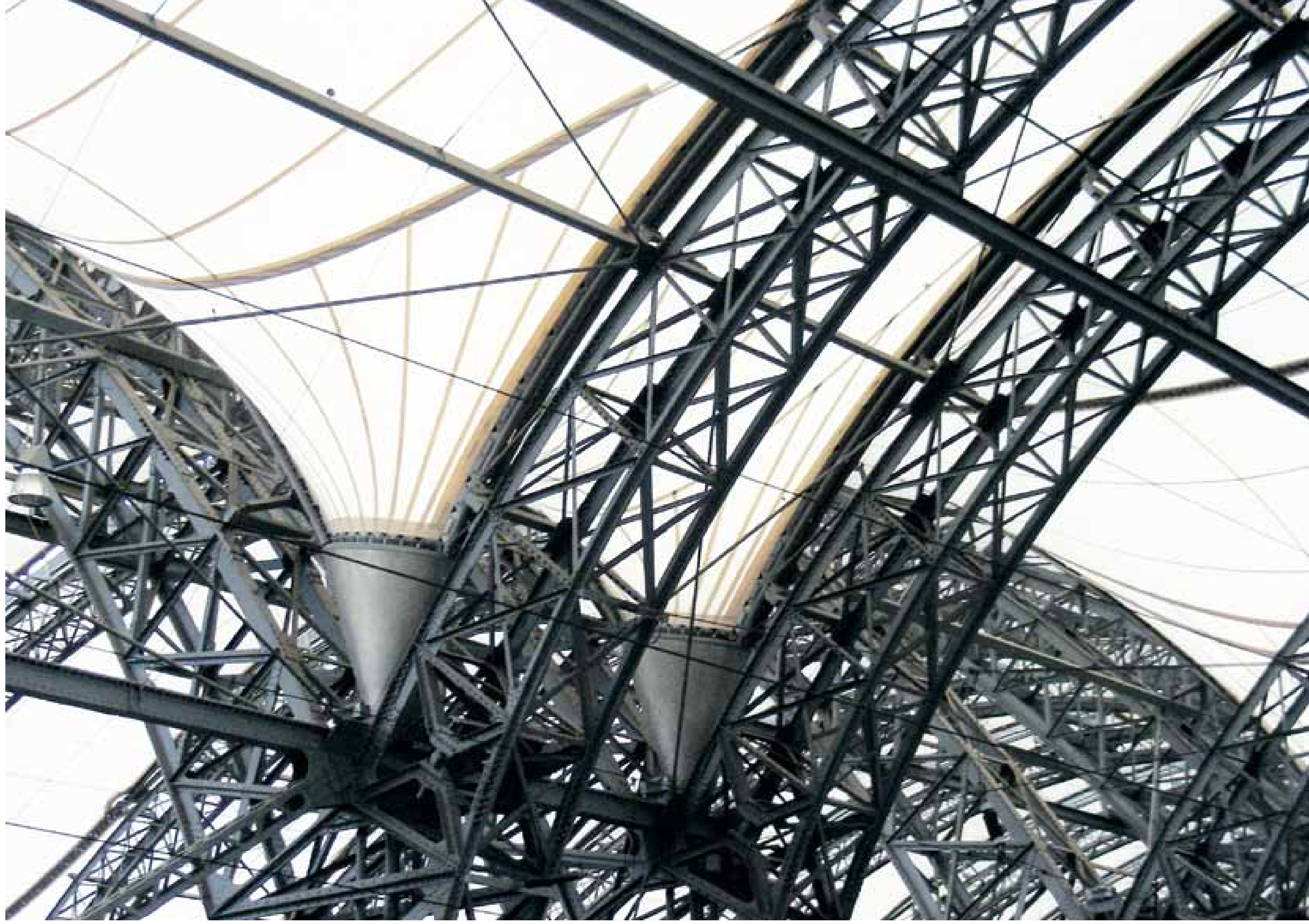
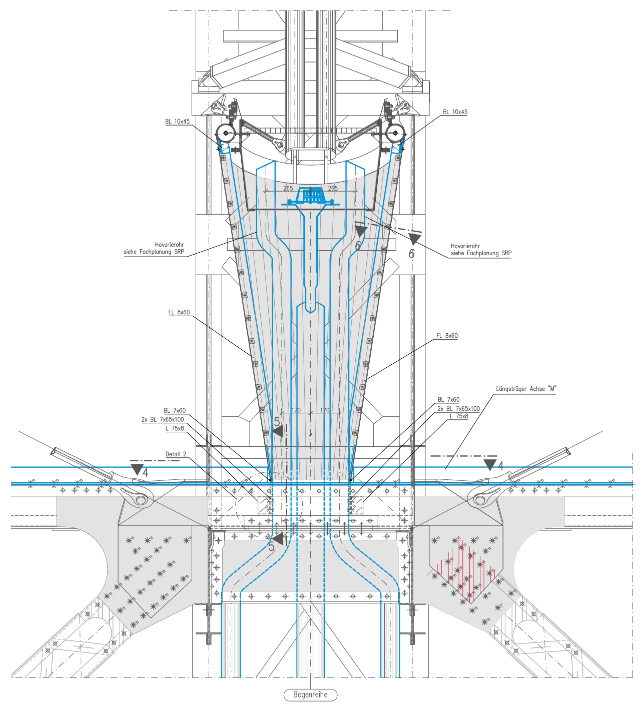


above: membrane roof– intake funnel
right: detail – intake funnel

Data and Facts	
Client	DB Station&Service AG
Architect	Foster & Partners, London
General planning	Schmitt Stumpf Fruehauf & Partner, Munich Services according to German Scale of Fees for Services by Architects and Engineers (HOAI) Project planning for buildings, open-air facilities and room-creating interior works Project planning Structural engineering including all construction stages under ongoing operation, makeshift constructions and mounting technologies, Structural inspection including as-built documents Performance related to plant outfitting
Work phases 1 to 8 for all above mentioned services	1 basic evaluation, 2 preliminary design, 3 draft design, 4 approval design, 5 final design, 6 preparation of tenders, 7 evaluation of tenders, 8 supervision Subsoil assessment and foundation-work consultancy (work phases 1 to 3)
Total length	240.50 m
Total width	121.75 m
Middle hall	approx. 60 m wide/35 m high
Side halls	approx. 32 m wide
Gross volume of platform halls	525,000 m³



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