Repairs of the Stuttgart Television Tower

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The history of the television tower

When television broadcasting was resumed in the Federal Republic of Germany on 25 December 1952 (after the Second World War), the Süddeutscher Rundfunk in Stuttgart planned the construction of a broadcasting tower for undisturbed reception in 1953. The Stuttgart civil engineer and university professor Fritz Leonhardt suggested the construction of a slender reinforced concrete tower instead of a steel lattice mast, which would be visible from afar at its high location. In addition to its broadcasting function, a viewing platform and a restaurant in the tower head were intended. Leonhardt, for whom the aesthetics of buildings were always a special concern throughout his life, considered a steel lattice tower ugly. Together with his colleague Walter Pieckert, Leonhardt developed a reinforced concrete tube designed to meet the structural requirements. Architect Erwin Heinle and interior designer Herta-Maria Witzemann, both also from Stuttgart, supported him in design and execution (Fig. 1).

Fig. 1: The first reinforced concrete television tower in Stuttgart, 1953–56

Fritz Leonhardt was an internationally renowned civil engineer; numerous wide-span bridges were built worldwide based on his plans. Leonhardt was not only an innovative engineer for bridges and towers, but also for lightweight structures such as the roofs of the Olympic facilities in Munich in 1972.

The foundation stone ceremony for the television tower took place on June 10, 1954. After 14 months of construction, an aesthetically successful and innovative tower was opened on February 5, 1956, which became a model for the rest of the world. Buildings based on the Stuttgart television tower were built for example in Toronto, Johannesburg, Frankfurt, Seattle, Wuhan Guishan, Moscow and Dortmund (Fig. 2).

In this context, one should also mention the television tower built in 1956–59 in Dequede in Saxony-Anhalt in the GDR, with a height of 185 m without antenna, planned by the project office of the Deutsche Post. This tower is similar to the television tower in Stuttgart, probably because Fritz Leonhardt was already involved as advisor during the planning phase. This tower has also been a listed monument since 1980 (Fig. 3).

The Stuttgart television tower is still used today. Although it no longer has a television antenna, it is still used for radio broadcasts and police radio. It also measures radioactivity levels every second on behalf of the state of Baden-Württemberg. In 1986 the tower was declared a special cultural monument and was added to the monument list of Baden-Württemberg.

The tower consists of the foundation body below ground, the one-storey entrance building, the tower shaft, the so-called Korb (head or basket), and the antenna on top. The upper viewing platform on the four-storey mast basket is 150m high; the total height including the transmitter mast is 217m. The diameter of the shaft is 10.80m at the base of the tower and 5.04m under the tower head. The diameter of the platform is 15.10m. The one-storey flat building, a typical example of 1950s architecture, is divided into the entrance area with access to the elevators, a service building and a small restaurant (Fig. 4).

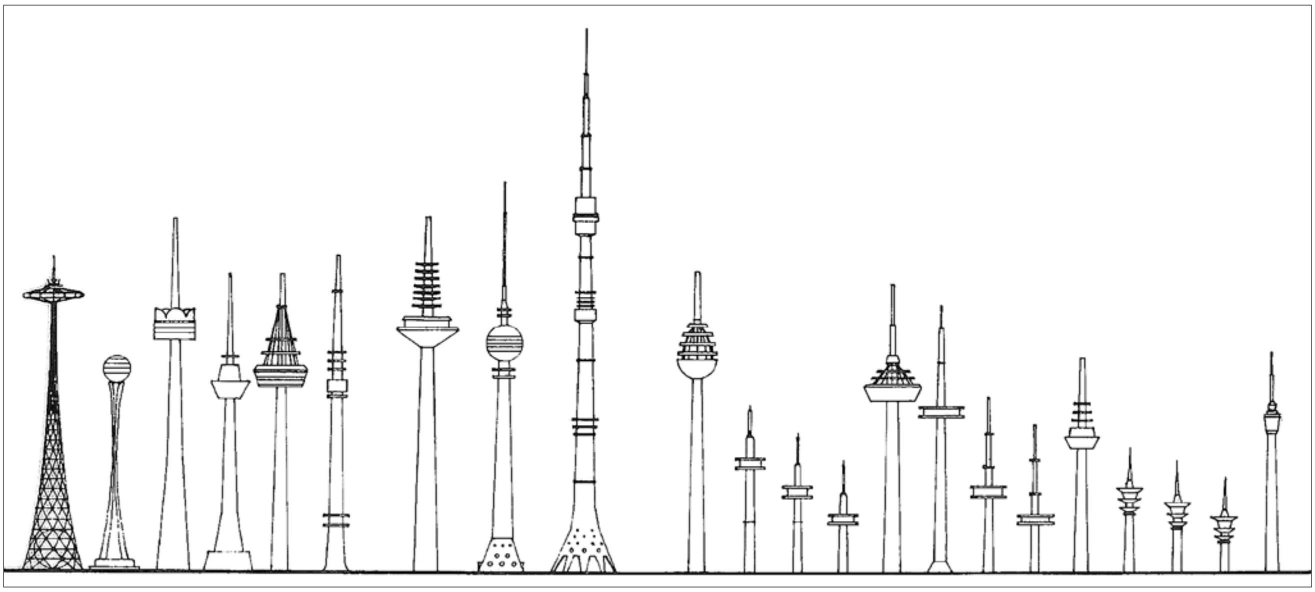

Fig. 2: Comparison of television towers worldwide (selection)

The tower head is reached by two elevators and a staircase in the shaft. The elevators travel at a speed of 5/m second, resulting in a travel time of approx. 36 seconds. The stairs are initially a spiral staircase up to a height of 75m and then a mono track staircase. Inside the tower shaft there were, apart from stairs and elevators, the entire supply lines for the technical broadcasting operation as well as for the restaurant and service facilities (Fig. 5).

The four main floors of the mast head contain the technical equipment of the transmitter, a theatre, a high-altitude restaurant with adjoining rooms, two staggered viewing platforms above and the anchoring of the steel antenna mast.

The foundation of the tower can be regarded as a special engineering innovation. The foundation, which is completely underground, consists of two cone-shaped truncated cones made of reinforced concrete and set against each other. They rest on a pre-stressed reinforced concrete slab with an outside diameter of 27m. This construction appears, according to a description by Fritz Leonhardt, "like a spatial framework of great rigidity". The foundation ends with a one-metre-thick reinforced concrete slab.

The slightly conical reinforced concrete tower shaft has wall thicknesses that taper from 80cm at the base to 19cm at the underside of the mast basket. Structural and dynamic loads, especially wind, and the aesthetic design played a role in the shape of the mast. The concreting process was carried out with a climbing scaffold familiar from chimney construction. 2.50m-high steel sheets were used as formwork.

The head of the tower also has a shape which in turn takes statics and form into account. The upper storey of the four storeys is cylindrical, the lower ones slightly conical and bevelled. In order to keep the wind resistance as low as possible, smooth aluminium without heels and profiles with rounded edges were used for the façade. With glittering reflections, the silver-grey outer skin was meant to "look like part of the atmosphere, depending on the lighting", enthused the builder Fritz Leonhardt (Fig. 11).

Fig. 3: Television tower in Dequede, GDR, 1956–59

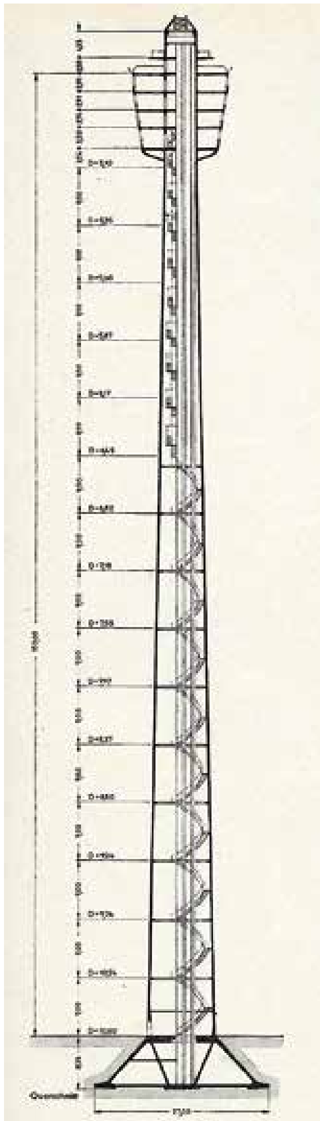

Fig. 4: Section through the Stuttgart television tower

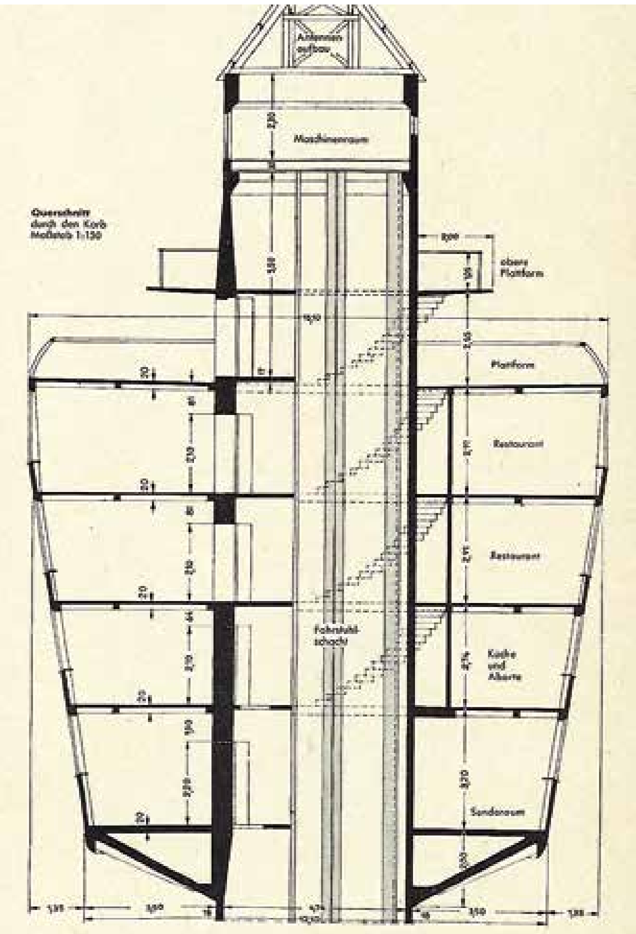

Fig. 5: The mast cage at a height of 150m for technical equipment, restaurant, theatre, viewing platform

Fig. 6: Longitudinal cracks in the tower shaft

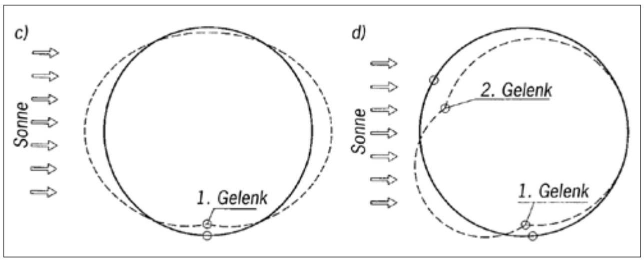

Fig. 7: Deformation of the tower shaft in changing temperatures

For 63 years now, the slender tower has been exposed to wind and weather and has survived storms and hurricanes that were stronger than the experiences prevailing at the time of construction. For the long-term preservation of the stability care, maintenance and safety work have therefore been indispensable.

The owner of the tower, today's Südwestrundfunk (SWR), entrusted the maintenance and repair work as well as the extensive and costly repair measures to the engineering office Leonhardt, Andrä und Partner (LAP), founded by Fritz Leonhardt, to ensure the long-term stability of the television tower. Together with partners, the engineering office regularly recorded and analysed damage developments and checked the reinforced concrete construction as well as the aluminium-clad mast cage with regard to the changed conditions since the construction period, such as the increase in wind speeds.

Concrete repair

As with the construction of the reinforced concrete tower, during the repairs and renovations of both the reinforced concrete shell of the tower (1994–96) and the aluminium shell of the tower basket (2003–06) pioneer work was done. No restoration experience was available.

As early as the 1980s, the temperature fluctuations caused by the winter sun (up to 35 degrees on the south side compared to minus degrees on the north side) were diagnosed as the main cause of the cracks in the tower shaft, which were initially visible from the inside. The cracks were filled with synthetic resin and stiffened inside with steel rings. However, these measures did not prove to be long-term and the cracks increased to the outside of the reinforced concrete pipe.

In 1993, before a further extensive repair of the cracks and concrete spalling, an extensive inventory and damage investigation was carried out in the various areas of the reinforced concrete structure. In the tower shaft, cracks with a total length of 232 m were mapped according to position, length and width. Due to the seasonal and daily changing temperature influences, the circular shaft deformed into an oval shape, in the course of which continuous cracks formed, which can be seen structurally as joints (Figs. 6, 7).

With this damage pattern and the specific conditions of the tower construction, there were no experiences that could be drawn upon. Renovation methods and technologies were extensively tested in the run-up to the renovation measures. The results of the investigations confirmed that the reinforced concrete shell was in a rather unexpectedly good condition with regard to concrete compressive strength and adhesive tensile strength. Compared to previous investiga-

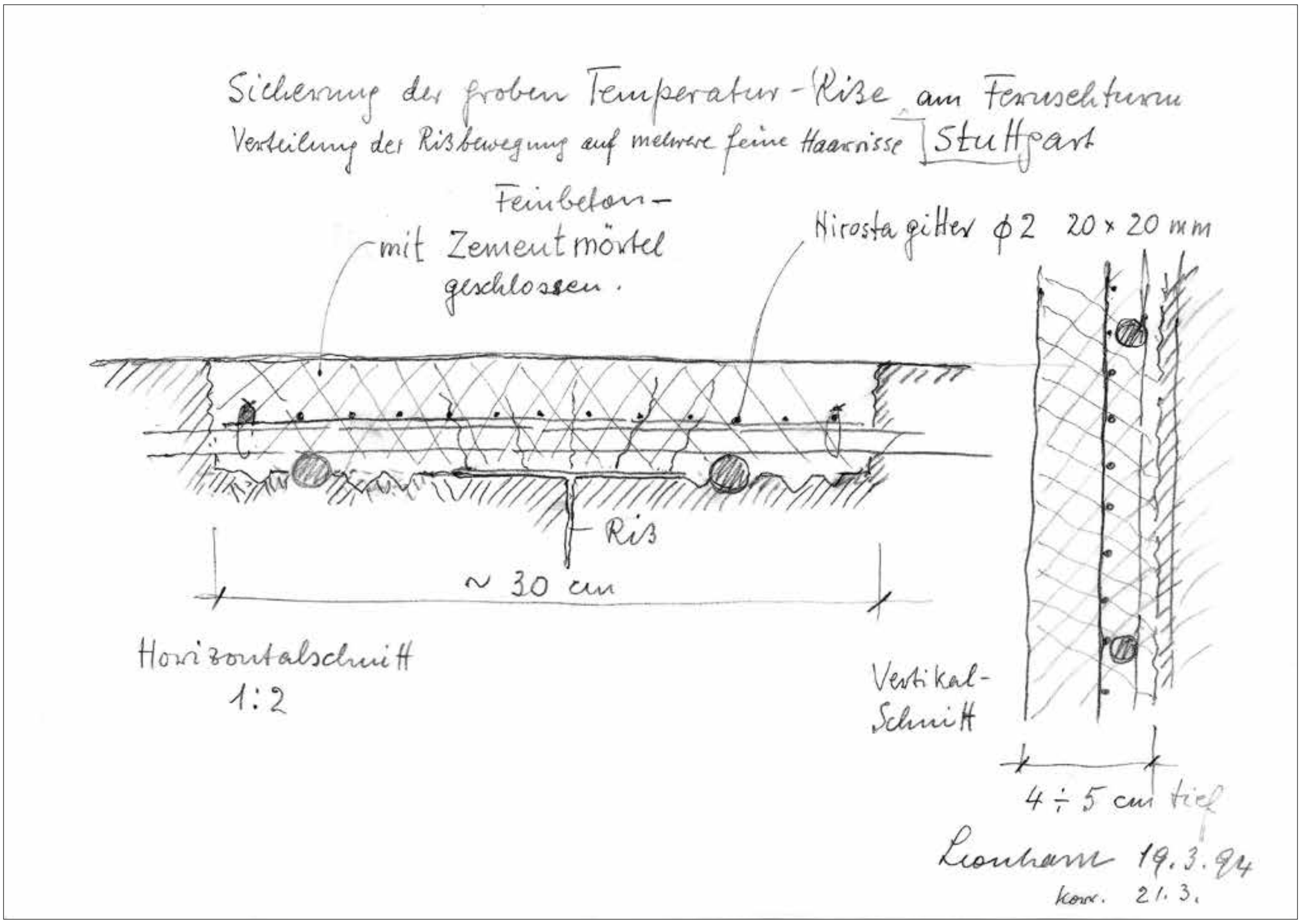

Fig. 8: Sketch for the restoration of the cracks by Fritz Leonhardt

tions in 1984, the damage pattern had not deteriorated significantly. Occasionally, damage was found in the horizontal construction joints from the time the tower was built.

In addition to the scientific, in particular material-technological preliminary investigations and the development of restoration alternatives, the office Leonhardt + Andrä involved the research and material testing institute of the University of Stuttgart (Otto-Graf-Institut – FMPA), as well as the companies Sika Chemie GmbH and Beton-Sanierungs-Technik GmbH for the execution.

The outer concrete surface also showed strong signs of weathering. Corroded reinforcement had led to spalling of the concrete coverings in some places. The testing of renovation methods on fairfaced concrete was in full swing on several buildings during these years.

First, the entire concrete surfaces were cleaned of loose components, moss and algae and coatings applied during earlier repairs with high water pressure. Concealed damaged areas were identified by tapping and closed with the now common methods of reinforced concrete renovation.

The cracks were each milled out with an 18.0cm wide and 2.0mm deep groove. Pores and blowholes were exposed with a wire brush. After dedusting the cracks, the crack-bridging primer was applied by brush. Adhesive tensile tests on the primed surfaces proved that the measure was successful. The cracks were masked with adhesive tape and filled by hand in four operations. After the work was completed, the entire tower shaft shell was water-blasted with high-pressure (working pressure 400 bar) to remove loose mortar parts and the cement paste layer on the surface. A considerable surface roughness and a high abrasion resistance were achieved.

In his old age, Fritz Leonhardt (1909–1999) was still actively involved in the development of suitable renovation methods, and these were ultimately successfully implemented (Fig. 8).

The conservation objective of the heritage authority was to preserve the surface structure and colour of the exposed concrete from the time the tower was built. A coating of the tower shell and truncated cone of the tower head was therefore initially postponed. From a conservation perspective, priority was given to reprofiling and colour matching of the repaired areas to the existing exposed concrete surfaces. Sample surfaces applied several times showed that an alignment could only be achieved to a limited extent and that the concrete surface without coating presented itself as a “patchwork carpet”. A film-forming, opaque coating was excluded. The infiltration of the coating in the area of shrinkage cavities and caverns could have led to detachment. In the end, it was agreed to apply a full-surface scratch and shrink hole filler with a final glaze to protect the surface on the one hand and to achieve a uniform overall appearance on the other. The concrete renovation system must be checked at regular intervals. According to a proposal made by Leonhardt in

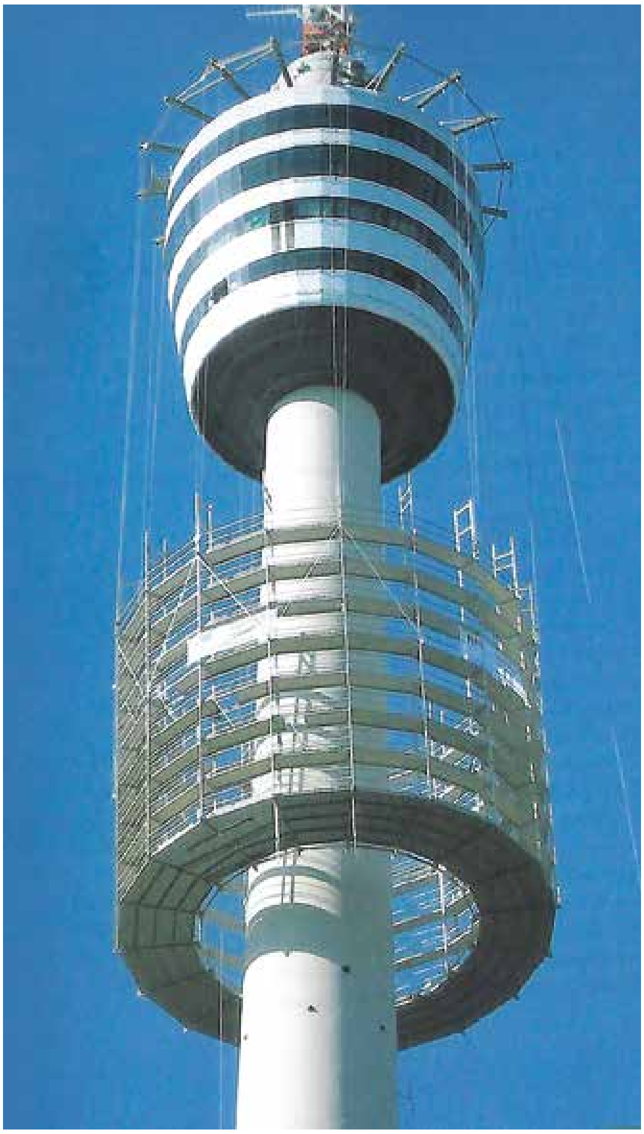

Fig. 9: Elevator on ropes for external repairs

Fig. 10: Replacement of facade elements

1994, for a shaft renovation ropes for mobile scaffolds were attached to the underside of the mast cage.

Renovation of the tower cage

In the early post-war period, not only the construction of such a reinforced concrete tower, but also the façade cladding of the mast cage made of aluminium were new territory. As a result, there was little experience with the service life and any necessary renovations.

For this repair and later maintenance work, cantilever girders were attached to the tower cage, on which a lift cage is installed on cables (Fig. 9). On a cantilever slab with annular conical formwork, the four floor slabs of the tower cage are supported on the outside on 18 reinforced concrete columns. In addition to each slab edge support, there is an aluminium facade post in the field, which extends the height of one storey in each case. It is suspended from the top and bottom of the reinforced concrete slab edge girder via a suspension structure. For this purpose, two horizontal anchor rails were attached to the upper and lower edges of the slab per suspension point in the slab edge beam. Between the facade posts, horizontal aluminium walers and vertically running anchor rails support the facade cladding and window elements. Cork insulation was glued to the outer aluminium cladding.

This renovation measure was also preceded by a detailed documentation of the condition and a damage analysis. At the locations examined, strong corrosion was observed at the anchoring points of the façade construction and on the load-bearing steel parts. The aluminium sheets were examined for decomposition by pitting corrosion. Based on the damage pattern, it was evident that moisture was transported between the aluminium outer skin and the interior cover. One cause was assumed to be the missing vapour barrier on the inside of the cork insulation glued onto the aluminium outer skin. In a manner characteristic for the construction period, the aluminium posts between the interior and exterior were not thermally separated.

However, the commissioned engineers were unable to assess the residual load-bearing strength of the structure and thus its fatigue strength, and due to the difficult conditions for repair work on the tower structure, they recommended that the facade be renewed. The risk of falling façade parts due to corroded, no longer friction-locked connections was to be eliminated as far as possible.

Corrosion at the connection and anchoring points made of steel angles as well as the desire for an energy-optimised façade by replacing the window elements in the restaurant area had persuaded the client and owner of the Südwestrundfunk tower to carry out renovation work on the top of the tower façade. The engineers' assessment was ultimately the decisive factor in the decision to renew the façade at the top of the television tower (Figs. 10, 11).

The new outer skin was constructed on the basis of the existing facade with thermally separated profiles and insulated panels. The new insulating glass consists of an 8 mm pane inside and a 12 mm pane outside with a 16 mm gap. The offices AIC Haipt GmbH, DS-Plan Ingenieure and Drees+Sommer, all from the Stuttgart area, were involved in the planning.

Fire protection and safety

Several times, the client and the local building supervisor demanded and implemented measures to strengthen the preventive fire protection. For example, a sprinkler system was installed in the tower basket in 1990. The double elevator, which was replaced in 2003, can be operated by the fire brigade for up to 30 minutes in the event of a fire. Last but not least, the theatre, which had been installed in the tower basket in addition to the catering facilities in 2006, was the reason why the building law office of Stuttgart issued the order to build secure escape routes for all levels in the tower basket. Until the implementation of these conditions, the use of the café, theatre and viewing platforms was prohibited with immediate effect. It was not possible to create an additional escape route. A second staircase on the outside of the tower was ruled out not only for monument conservation reasons. Therefore, fire protection experts were consulted in the search for possible solutions, who were able to prove that they were competent in the field of cultural monuments (Halfkann and Kirchner, Erkelenz). The solution approach for a fire protection concept that could be approved included the following points:

- Reducing the risk of fire;
- Rapid detection of the spread of a fire by setting up a comprehensive fire and early warning system and targeted and controlled alarming;
- Optimisation of fire protection and smoke extraction by removing ignition sources. In computer simulations wind dependent smoke developments and distributions were tested;
- Sealing off and encapsulation of fire loads through the use of fire protection cables in conjunction with electronic temperature monitoring of the transmission cables;
- Extension of the sprinkler system and nitrogen extinguishing system;
- Improving and securing escape and rescue routes by creating fire compartments in the basket and on the ground floor and installing escape doors;

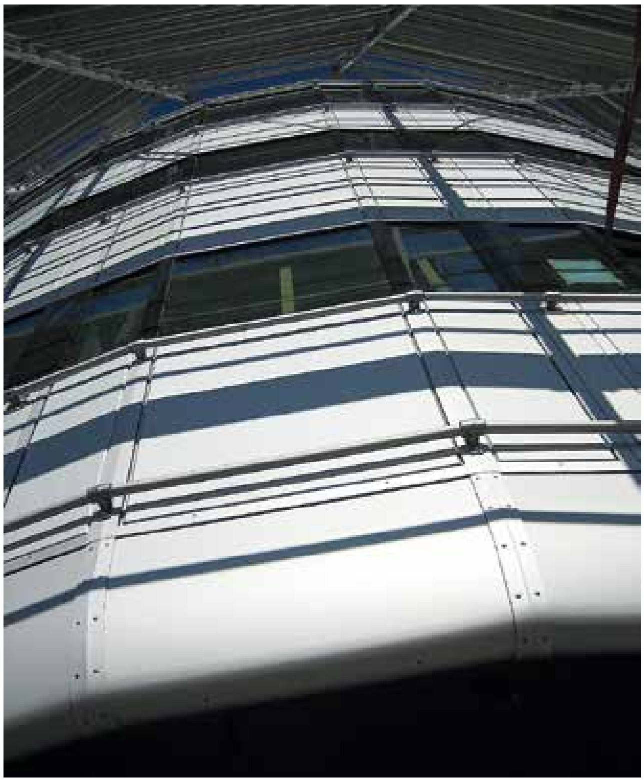

Fig. 11: Renewed facade of the mast basket

- Development and implementation of a detailed evacuation concept;
- Optimisation of the organisational fire protection and the fire brigade.

In order to concretise the concept, proof of sufficient stability in the event of a fire was required. Computer-aided fire simulation calculations were carried out to determine the thermal impact on load-bearing and stiffening components of the tower basket and to investigate the possible formation of smoke in the area of the waiting positions on the two viewing platforms (Fig. 12).

The fire protection concept also assumes that the number of people in the tower needs to be limited. As a basis for this, there are the research results of the Moscow scientists and engineers Michailowitsch Predtetschenski and Iwanowitsch Milinski (1965), who investigated the flows of people in buildings, their behaviour in time and density.

A maximum of 320 people (visitors and staff) are allowed to stay in the tower at the same time. For the theatre level, the maximum number of persons is set at five groups of 14 people each, i.e. 70 people (visitors including staff and artists etc.), in order to complete the evacuation in a maximum of five elevator rides of approx. 3 minutes each, i.e. 15 minutes. The number of people in the tower basket is limited to 150, which can be guaranteed by the number of seats and the space available. The engineering certificates for the evacuation were based on this number of persons and an evacuation concept was derived. This is fundamental for both the elevator evacuation and the group evacuation via the staircase in the tower shaft. A turnstile system was installed in the foyer to guide, count and limit the number of visitors.

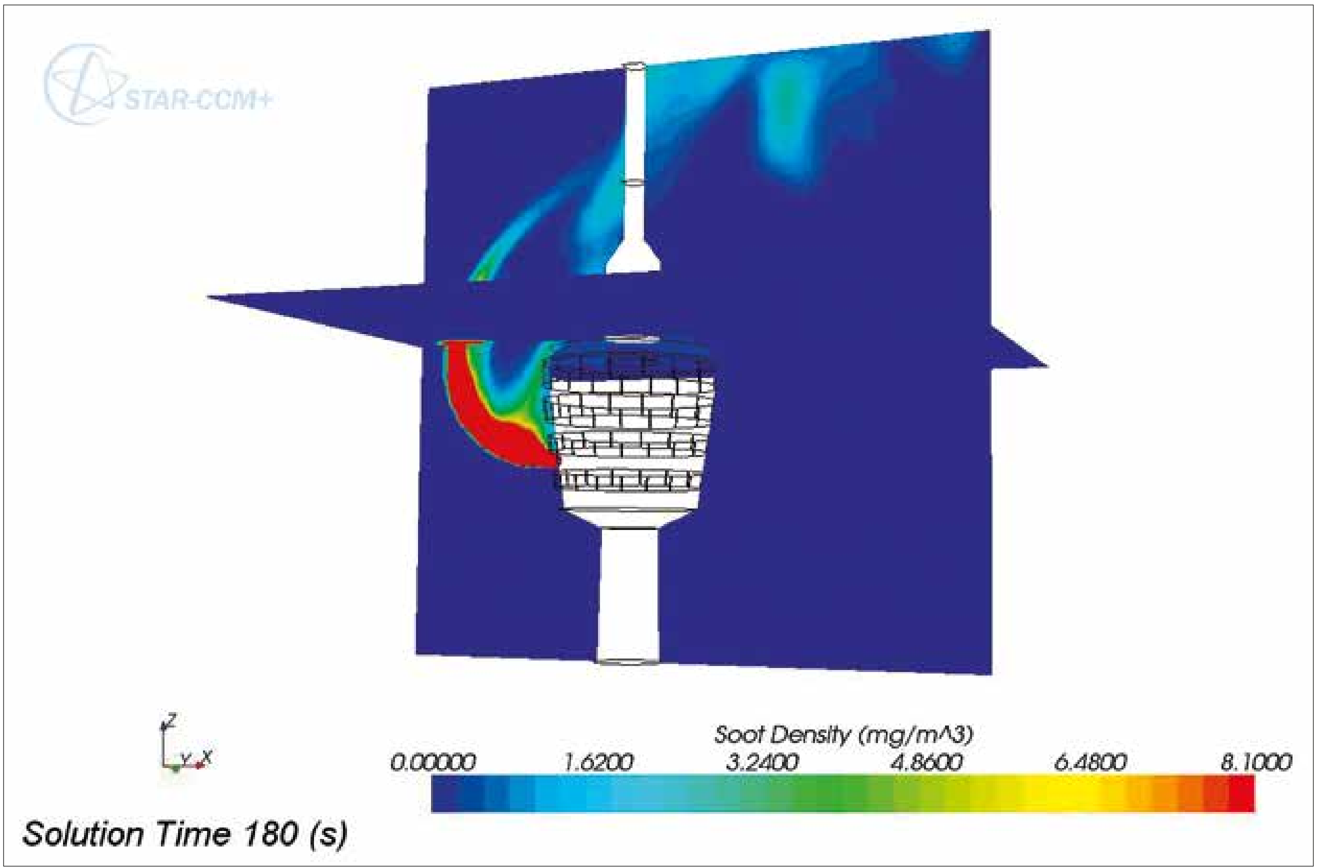

Fig. 12: Simulation of smoke development in case of fire

As an essential retrofitting measure of the feasibility study, the encapsulation of the cable fire loads in the tower shaft was planned in order to avoid an impairment of the escape routes, staircase and lift, which are also located in the shaft.

The transmission and power cables, which led openly upwards in the shaft next to the elevator, were sheathed in flame-retardant material and thus routed in two separate shafts. The next step was to produce a cable shaft for the high and low voltage cables, into which non-combustible fire protection insulation flakes were blown after the cable pull and the cable enclosure. Horizontal fire brakes by means of bulkheads were provided every 1.50 m. Automatic monitoring prevents smouldering fires on cables that are no longer visible. Flame retardant materials and technologies were used to reduce the risk of fire. The existing escape routes, staircases and double elevators, which can be operated by the fire brigade for up to 30 minutes in the event of a fire, were upgraded. The measures ultimately resulted in comparatively minor interventions in the existing structure. They were supported by the monument conservation authority to enable continued public accessibility and use of the television tower.

The interior design of the public rooms was renewed according to today's ideas and regulations. Attention was paid to compatibility with the monument and its history.

On 27 November 2016 the Stuttgarter Zeitung wrote: "The waiting is over after three years: the Stuttgart television tower opens its doors again at the end of January after three years. The new fire protection technology sets global standards."

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