Membrane-skin and cable-net cooling towers

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Membrane-Skin and Cable-Net Cooling Towers

Tours de refroidissement, avec une couverture d'aluminium posée sur un réseau de câbles

Kühltürme mit Membran- und Seilnetzmantel

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General description and load bearing behaviour:

The main feature of the new type natural draught cooling tower, presented here, is its prestressed membrane- or cable-net skin, replacing the reinforced concrete shell as with conventional towers (Fig. 1).

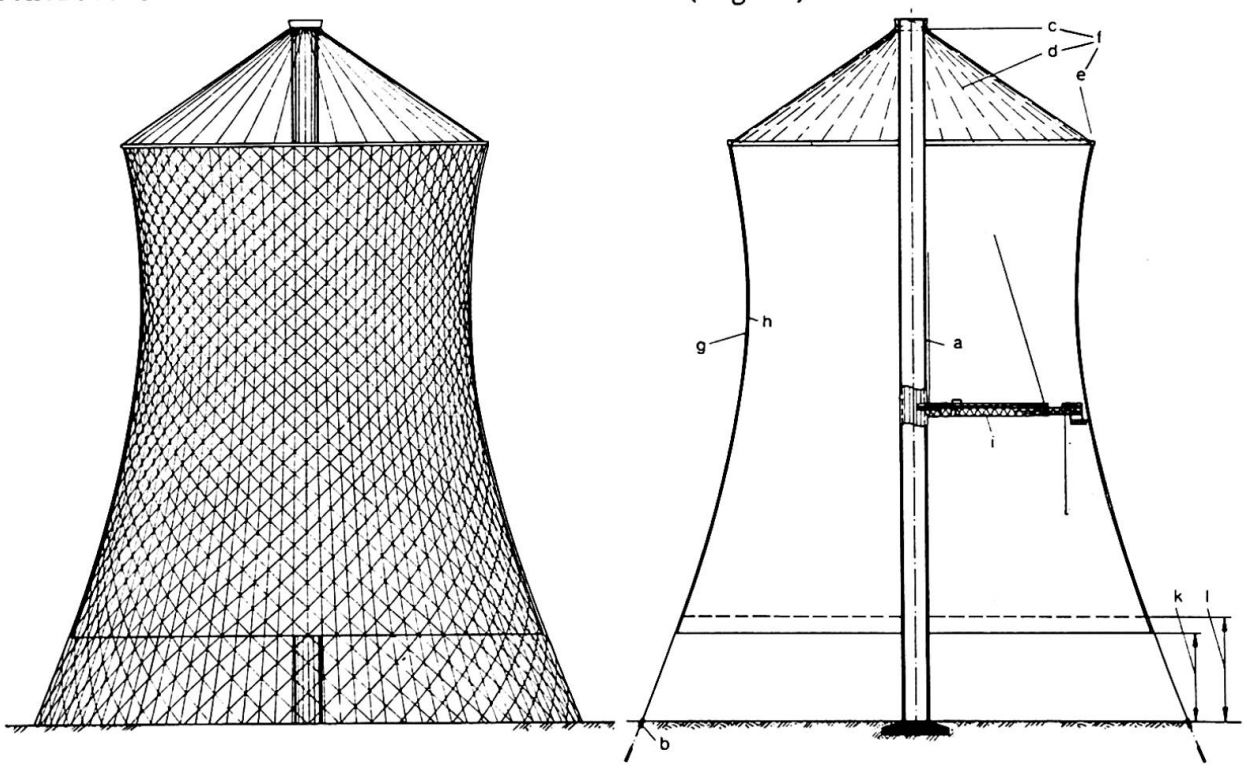


Fig. 1 a Mast, b Foundation ring with soil anchors, c Hubring, d Spokes, e Compression ring, f Spoke-wheel, g cable-net mantle, h Cladding, i Telescopic crane, k Air-intake opening, l Cooling elements resp. trickle plant

The one-sheet hyperboloid, commonly used for cooling towers, meets already excellently the shape requirements of negative curvature for prestressing. In a correspondingly cut membrane, closed in its circular direction, the prestressing forces required are to be applied only from its upper and lower borders to produce tensile stresses in the membrane at any point and in any direction. For the membrane always to act in tension, the amount of tension from prestress is required to be larger than the principle compressive stresses under any loading condition (Fig. 2).

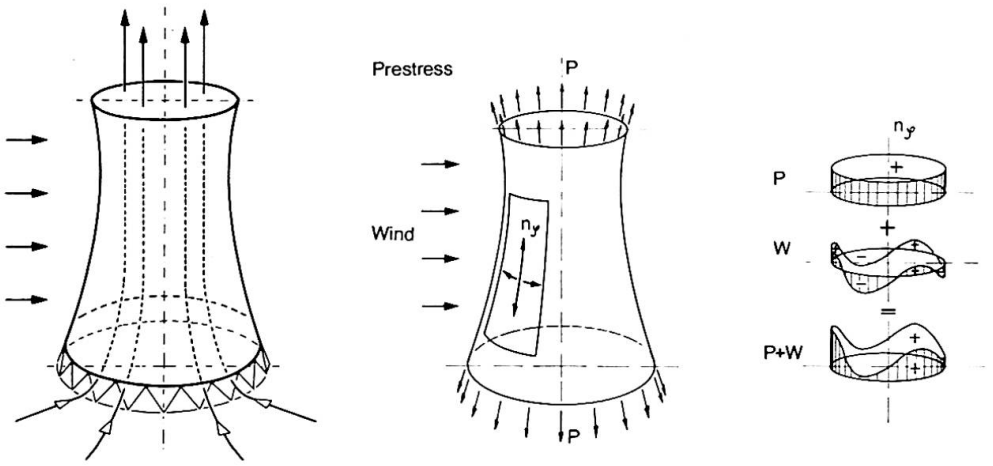


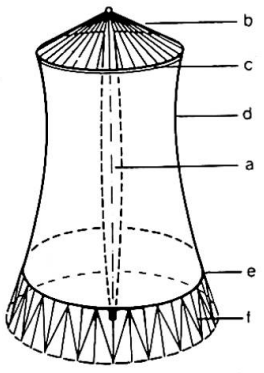
Fig. 2

Such a prestressed membrane skin behaves as an ideal membrane shell. When compared to a non-prestressed, and therefore necessarily thick shell with bending stiffness, as in the case of the conventional concrete cooling towers, it has certain decisive advantages:

- Local wind gusts will not cause bending stresses in the wall, since it has no bending stiffness. They will be distributed in the prestressed membrane through small deformations and minor additional direct stresses.

- There will be no stability or buckling problems, since the prestressed membrane never acts in compression. The tensile strength of its material may, therefore, be increased to the technically possible limits and be fully utilized. For this reason, materials such as high tensile steel sheets, fabric or cable nets are particularly suitable.

In order to introduce the prestressing forces into the membrane and to stiffen it against non-extensional deformations, it is provided with a foundation ring at the base and a compression ring at the top end (Fig. 1 + 3). The compression ring is suspended by inclined radial ropes, similar to the ring in a spoke-wheel, from the top of a mast.



a Mast
b Spokes
c Compression ring
d Membrane mantle
e Intermediate ring
f Rod or cable truss

Fig. 3

The mast is placed at the center of the tower and acts under pure compression. The load bearing behaviour of the membrane shell will also not change if it is raised above ground level to a height determined by the air-intake requirements of the cooling system, provided that the membrane is replaced by a triangular mesh truss formed by ropes or bars.

The spoke-wheel, proposed for the suspension and the prestressing of the membrane shell, acts additionally as a perfect stiffening slab. By it the stresses in the shell will be much more uniformly distributed as compared to a shell without a stiffener at its top.

For cooling towers with a large height/width ratio it may be advisable to provide, in addition to the spoke-wheel at the top, intermediate horizontal spoke-wheels at various levels to approach more and more the optimum straight-line stress distribution of the fully stiffened shell. Since the size of the membrane forces is responsible for the potential energy of the tower, and as the maximum compressive forces in the skin mainly determine the amount of pre-stress required and, therefore, also the compressive force in the mast, the effect of these spoke-wheels is directly reflected in the costs of such cooling towers.

Structural design and erection of a first cable-net cooling tower:

At Schmehausen, West Germany, the first cable-net cooling tower for a nuclear power plant is presently (end of 1975) nearing completion. Its diameter at the base is 141 meters and the diameter of its compression ring at the top 91 meters. The mast is 180 meters high, with the height of the compression ring being 146 meters above ground level (Fig. 4).

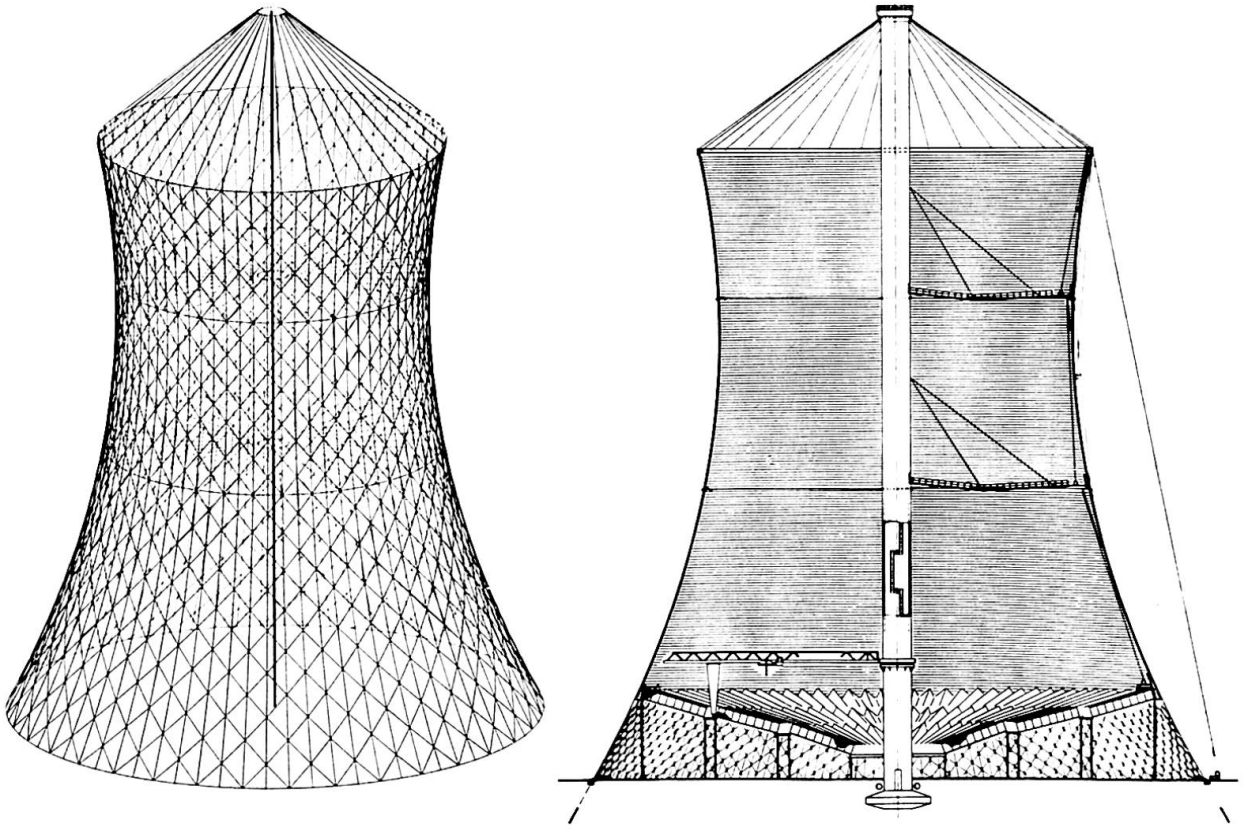


Fig. 4 The cable-net tower for the nuclear power plant at Uentrop/Schmehausen of the HKG im VEW-Kraftwerk Westfalen.

Instead of making direct use of a membrane as described above (Fig. 3), its skin consists of a prestressed cable-net which is further covered by an air-tight cladding. The cable net, with respect to its load bearing behaviour, must necessarily have a triangular mesh form, in order to act as a membrane. The arrangement of the cables was chosen in such a way, that the total net with its 46,000 m^2 can be prefabricated out of only two different ropes, as all diagonal ropes on the one hand and all meridian ropes on the other are exactly equal.

Since the central mast only acts under compression, it is made out of reinforced concrete. It was erected simultaneously with the casting of the circular ring foundation for the anchorage of the cable net (Fig. 5). This reinforced concrete ring is anchored into the ground by prestressed soil anchors.

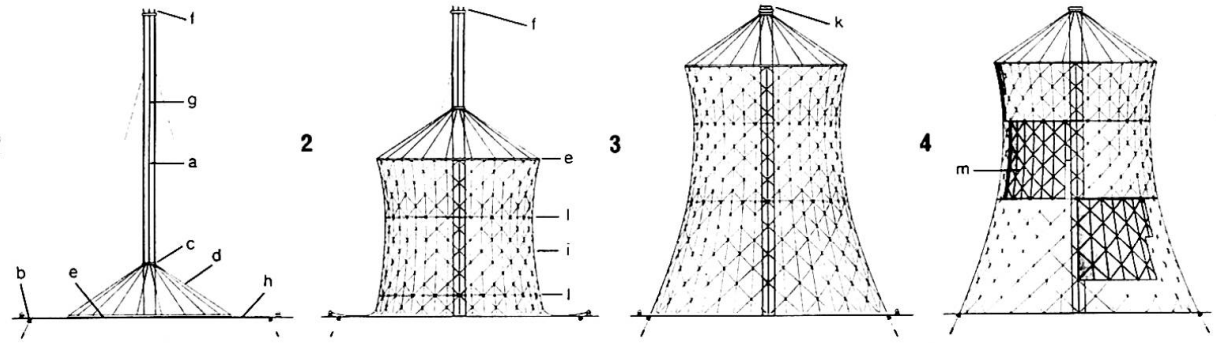


Fig. 5 a Mast, b Foundation ring with soil anchors, c Hubring, d Spokes, e Compression ring, f Lifting device, g Lifting ropes, h Net ropes, i Cable-net mantle, k Prestressing device, l Spoke-wheels, m Cladding.

Next the outer compression ring of the upper spoke-wheel and its central hub-cum-lifting ring were assembled on the ground. Both rings are steel hollow-box sections, 80 x 120 cm and 60 x 100 cm respectively (Fig. 6).

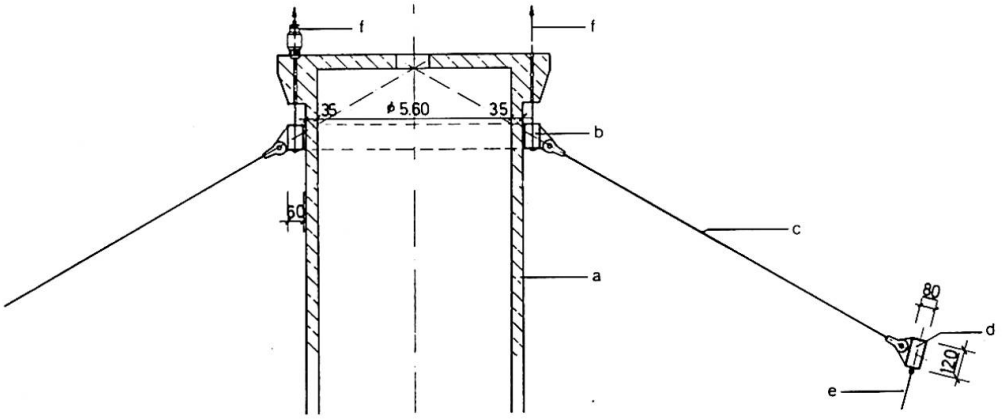
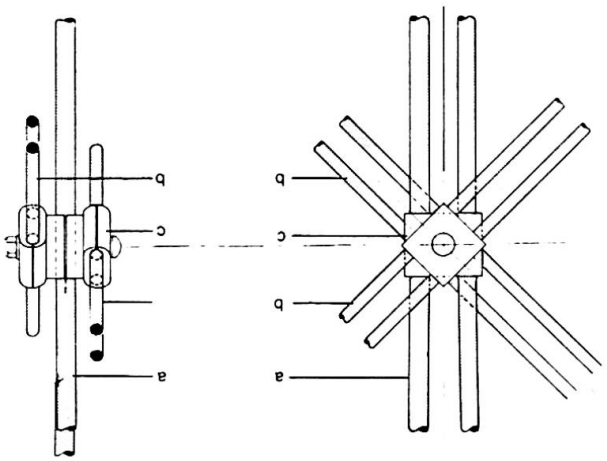


Fig. 6 a Mast, b Hubring, c Spoke-rope, d Compression ring, e Cable-net, f Lifting resp. prestressing device.

The 36 spokes, fabricated using 78 mm diameter locked-coil ropes, were connected to these two rings. In the meantime, at the top of the mast a lifting device was installed from which the central hubring was raised by three lifting ropes. The cable-net was then attached to the compression ring and continuously assembled whilst the hubring and consequently the spoke-wheel was lifted. For this purpose the type of net ropes, already developed for the Olympic roofs in Munich, were most suitable. These ropes consist of two parallel strands with aluminium clamps, press-fitted in the fabrication workshop (Fig. 7).



a Vertical or meridian ropes;
d = 25 mm
Strand from 37 Alumoweld wires

b Diagonal ropes;
d = 20 mm
Strand from 19 Alumoweld wires

c Aluminium press-fitted clamps

Fig. 7

They guarantee an exact pattern of the net through a continuously equal distance between the corresponding knots. For assembling the net on the site, there is only one bolt at each knot required for the connection of the three layers of the rope. To guarantee long-life corrosion protection, the strands are spun from so-called alumoweld wires, which are steel wires, covered with an aluminium coating of as much as 25 % of the total section.

After the lifting process was finished, the cable-net was connected with the ring foundation (Fig. 5). Next the hubring at the top of the mast was further lifted until the prestressing force required was reached. According to its pattern, the cable-net then assumed its exact geometry.

In accordance with the principles mentioned before, the Schmehausen tower is being constructed with two additional horizontal spoke-wheels (Fig. 4 + 5). Each consists of an outer compression ring on the net surface and an inner tension ring encircling but not touching the mast. Both rings are connected by 36 post-tensioned radial ropes of 32 mm diameter. They were also assembled at ground level, simultaneously with the assembling of the cable-net, and lifted together with it. After prestressing the cable-net and connecting the hubring with the top of the mast and thus finishing the structural construction of the tower, the cladding is attached onto the inside of the net.

The cladding, in this case, consists of corrugated aluminium sheets, which are bolted to the knots of the cable-net and are joined in such a way that they are able to follow the deformations of the cable-net under wind load. The net on the outside yields a surface roughness which minimizes the wind suction at the flanks of the tower, as could be shown by wind tunnel tests.

Outlook:

Since there is almost no limitation to the size of membrane- or cable-net cooling towers, as it is the case with concrete towers, this new type can be expected to become most advantageous for the future large and very large cooling towers. It will with increasing size become comparatively easy to erect and more economical, mainly if the required width is to be large against the height (Fig. 8).

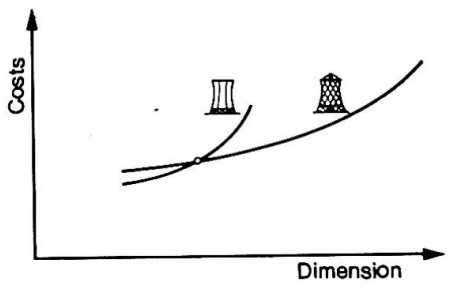


Fig. 8

Under seismic conditions it will in any case be superior to the conventional type, because, due to its small mass, even the most severe earthquakes cause less forces than wind. It should further be mentioned that this type of cooling tower is not at all sensitive to foundation settlements. If in mining areas very large settlements are expected, turn-buckles can be provided in the ropes along the foundation for easy adjustments.

This type of structure permits such large dimensions for cooling towers where the area inside the tower yields enough space for a whole power plant. The mast may then serve, at the same time, as a chimney. It is also possible to design the cable-net as an anti-aircraft net for any nuclear power plants, built inside the cable-net cooling tower.

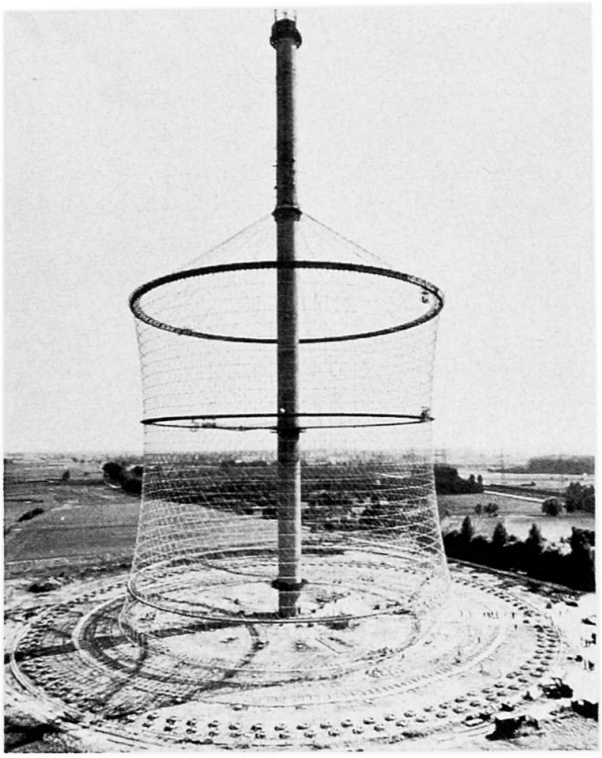


Fig. 9 The cable-net tower for the nuclear power plant at Uentrop/ Schmehausen. Completed works up to Sept. 75 (see Fig. 5, construction phase 2).

The cooling tower at Schmehausen (Fig. 4 + 9), as described in this paper, is a joint development of the Balcke-Dürr AG, Bochum, and Leonhardt + Andrä, Consulting Engineers, Stuttgart, with J. Noesgen being the main collaborator of the authors. Balcke-Dürr/GEA, Bochum, are the general contractors and Krupp Industrie- und Stahlbau, Goddelau, the contractors for the cable-net tower. The computer program was developed by D. Scharpf of the RIB, Stuttgart.

SUMMARY

A new type of natural draught cooling tower is presented, which is mainly of advantage, if either one of the following conditions is required: large dimensions (specially large width to height ratio), seismic conditions and soil settlements.

RESUME

Une nouvelle tour de refroidissement est décrite, qui est surtout avantageuse si l'une des exigences suivantes est remplie: grandes dimensions (particulièrement grand diamètre par rapport à la hauteur), construction en zone sismique ou sur des terrains exposés aux tassements.

ZUSAMMENFASSUNG

Ein neuartiger Naturkühlturm wird beschrieben, der vor allem dann vorteilhaft ist, wenn eine der folgenden Forderungen gestellt wird: grosse Abmessungen (besonders grosser Durchmesser gegenüber der Höhe), Bau in Erdbebengebieten oder setzungsempfindliche Böden.