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Experience of Cupola Collapse with a Diameter of 237 m

Expérience tirée de l'effondrement d'une coupole de 237 m de diamètre

Erfahrung aus dem Einsturz einer 237-m-Kuppel

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SUMMARY

The steel dome of 237 m in diameter collapsed in Russia in 1986. The construction of the dome and its finishing were completed. The load-carrying structure were made as two-layer latticed bar shell. Shortly before the collapse the outdoor air temperature changed from -20°C to +1°C during six hours. Due to the non-uniform heating some of the shell bars lost their stability and this caused the collapse.

RÉSUMÉ

En 1986, une coupole en acier de 237 m de diamètre s'écroula en Russie, après l'achèvement complet de sa mise en oeuvre. La structure porteuse se composait de deux coques formées de barres en treillis. Juste avant l'effondrement, la température de l'air ambiant s'éleva de -20°C à +1°C en six heures. La rupture de stabilité de certaines barres de treillis, par suite de leur échauffement non uniforme, provoqua l'écroulement de la coupole.

ZUSAMMENFASSUNG

In Russland stürzte 1986 eine Stahlkuppel mit 237 m Durchmesser ein, nachdem die Montage und Fertigstellung vollzogen waren. Das Tragwerk bestand aus einem zweischschaligen Raumfachwerk. Kurz vor dem Einsturz stieg die Aussenlufttemperatur innerhalb sechs Stunden von -20°C auf +1°C. Durch die ungleichförmige Erwärmung büssten einige der Fachwerkstäbe ihre Stabilität ein, worauf der Kollaps eintrat.

There was a competition announced in 1981 for designing of a long-span building 115 m high with a span of 250 m.
The building was meant for testing the equipment used for electric power lines at a voltage to 2000000V. It was suggested that the construction site should be located at a short distance from Moscow. Two designs were submitted for examination at the last stage of the competition.
Desigh No 1 elaborated by a team of Moscow civil engineers presented a building shaped as a flattened ellipsoid 237 m in eduator diameter. The building height was 119 m. See Fig.1.
The principal load-carrying structures were designed as a two-layer latticed shell at a spacing of 2.5 m between the upper and lower chords. The shell upper and lower chords were made of twin angles. The lattice between the chords was made of tubes welded to the angle flanges. A diaphragm 1,5 mm thick of weatherproof steel was welded to the upper members of the shell. The diafragm served as roofing and made the bars stable.
The heat-insulated boards of the suspended ceiling working as fire protection of the carrying structures at the same time were secured to the lower chords of the shell. The erection members were connected by high-strength bolts. The total weight of the steel structures was about 11000 tN.
Design No.2 was elaborated by a team of Leningrad (St.Petersburg) engineers. It was a structure 128 m in height made of a cylinder like part 80 m high and a hollow domelike roofing 227 m in dia with a boom of lift 47 m. See Fig.2. The cyliderlike framework was made of columns connected by cross-braces and the dome was designed as a circular ribbed structure. The total weight of the structures made about 11500 tN.
Both designs were supported by the necessary calculations of the structures made in accordance with the Russian Building Code (dead weight, snow load, wind load, thermal effect).
Design No.1 was chosen for construction mainly because of the architectural expressiveness of the building and the criteria unlikeness.
The main structures of the dome were erected by the middle of 1984. See Fig.3a. The erection and construction work completed in 1985. The overloaded members were checked for force increment at erection of technological equipment premises 600 tN in weight

at an elevation of +106.7 m. The test results gave good coincidence of the design model and the real work of the structures.

In 1986 the dome collapsed. Since it was early morning, there were no victims. Before the collapse took place, the construction site underwent very rare meteorological condition. The air temperature remained -20°C during 20 days. Then during 6 hours the temperature changed to +1 °C. Three hours after this the dome collapsed.

Let us analyse what changes happened in the stress conditions of the structures under such a sudden change of air temperature. The space 2.5 m high between the upper chord covered with cold steel sheets and the lower lagged chord turned to something like a thermos with a temperature of -20°C. The bars of the upper cold chord warmed up faster under the outside sharp heating than the bars of the lagged lower chord - see Fig.4. The difference in temperature of the chords according to the calculations could reach 15°C. Nonuniform heating of one chord to 1 °C gave the stress increment to 3 MPa in some of the bars and at 15°C this value made 45 MPa or almost 30% critical strength of the steel. Most probable the additional stresses brought mostly loaded bars to the loss of stability and caused the collapse.

The imperfectly thought-out solution of the enclosing structures resulted in the design diagram in the form of a latticed dome highly sensitive to the nonuniform temperature effect.

Conclusion.

1. When designing long-span structures it is necessary to use statistically treated meteorological data on the sharp changes of outdoor air temperature with determination of the temperature change speed and range and probability for 25, 50 and 100 years.

2. It is necessary to perform heat engineering and static calculations for the long-span structures for the stage of construction and operation in sharp condition of air temperature change in the building area.

3. When desighing the enclosing structures it is necessary to provide for equal temperature conditions of the load carrying structires.

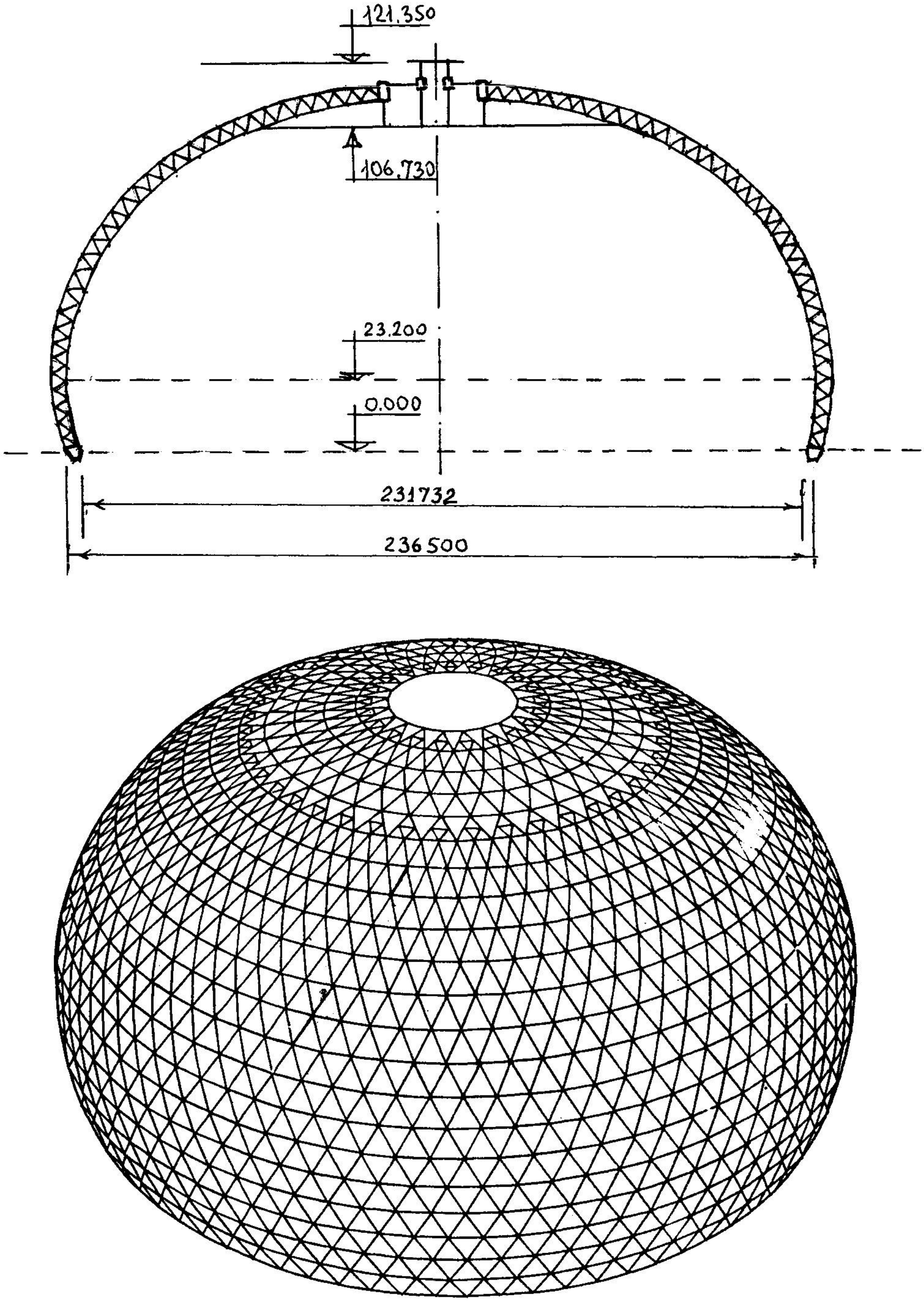


Fig. 1

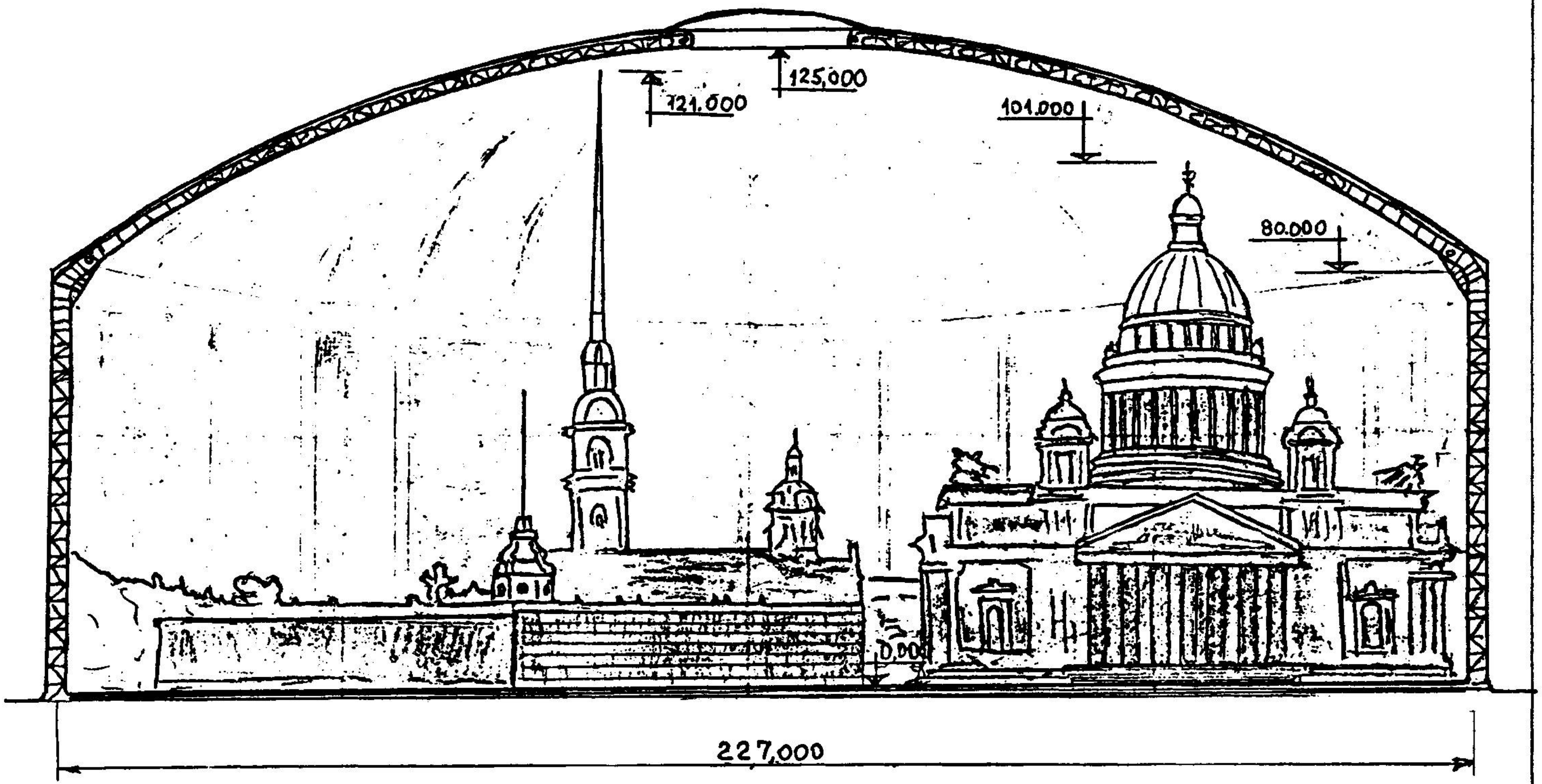
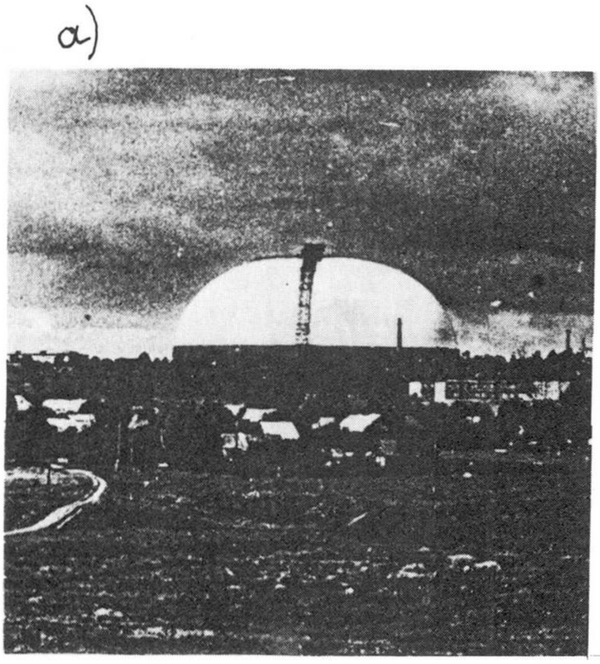


Fig 2.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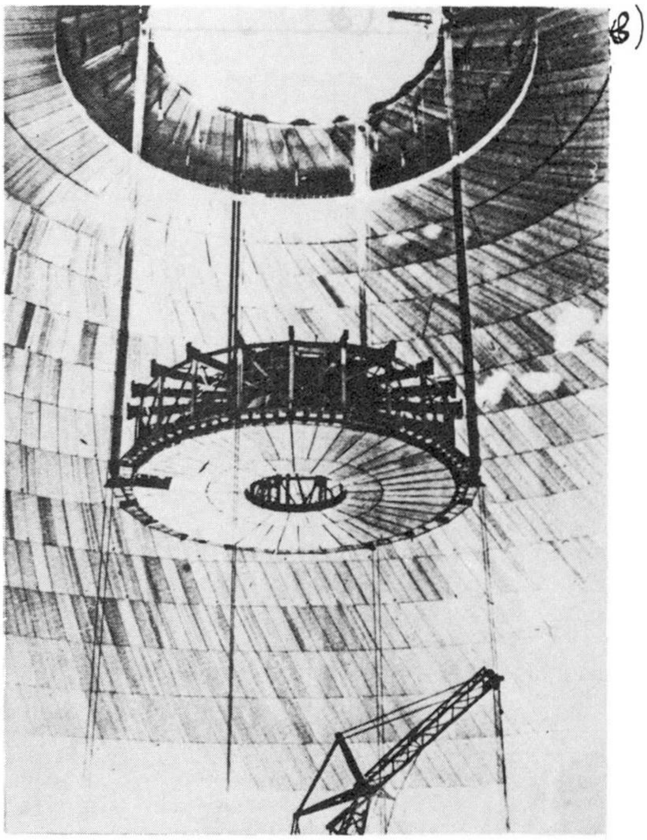
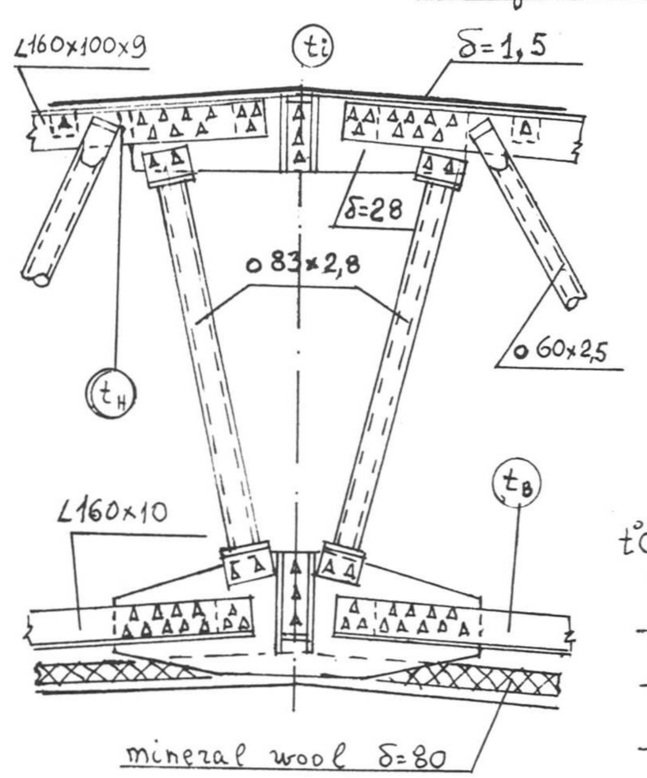
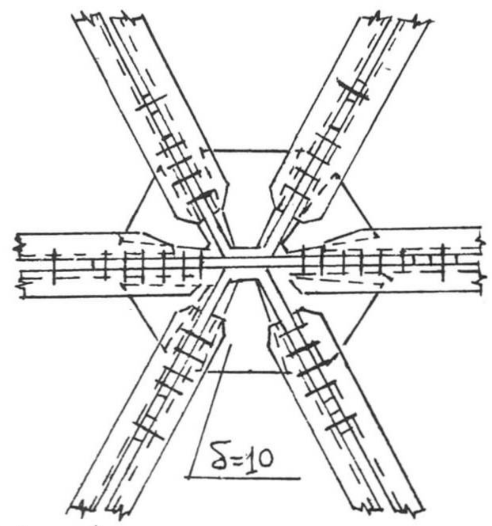

в)

Fig. 3.


∠160×100×9
ti
δ=1,5
δ=28
○ 83×2,8
○ 60×2,5
tH
tB
∠160×10
mineral wool δ=80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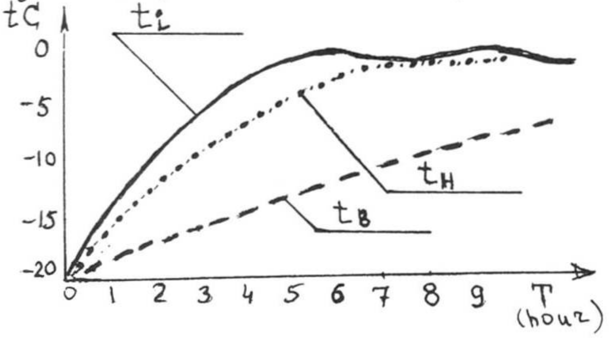
t°C
ti
0
-5
-10
-15
-20
tH
tB
0 1 2 3 4 5 6 7 8 9 T
(hour)

Fig. 4.