PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

EXPERIENCES OF OFFSHORE LIGHTHOUSES IN SWEDEN

Erling Reinius — Vattenbyggnadsbyrån (VBB) and Royal Institute of Technology

Stig Haggård — Swedish Board of Shipping and Navigation

Edgars Ernstsons — Swedish Board of Shipping and Navigation Stockholm, Sweden

During the last thirty years many offshore lighthouses founded on the sea-bed and composed of a substructure of a caisson and a superstructure of a cylindrical tower have been built in Sweden[1]. In most cases they have replaced light-ships or buoys in order to make the service more dependable also in winter-time and to reduce the running cost.

The first large size offshore lighthouse was ÖLANDS SÖDRA GRUND[2] which was constructed during 1947-1951. It is placed in the Baltic on 12 m depth about 22 km off the nearest coast. The caisson was constructed in a sheltered place and then floated out to its site at sea and sunk down to a prearranged bed on the seabottom. The construction at site of the superstructure with living quarters and tower and further the installation of all equipment took long time due to transport and weather difficulties, rough sea, etc. The lighthouse was first manned but operates now automatically and is unmanned. 1970 it was provided with a helicopter platform on top of the tower.

The construction of this lighthouse showed that for an economic design of offshore structures as much as possible of the work should be carried out ashore. The costly and dangerous work at the offshore site should be reduced to a minimum.

These considerations resulted in construction methods which made it possible to carry out the construction work as well as the installation work ashore, and then to tow the whole structure to its site at sea. An early development was the telescopic method of construction[3]. In this method the superstructure is constructed as a separate caisson inside a bottom caisson, thus giving a low gravity centre and a sufficient floating stability to the caisson set. After positioning at the lighthouse site, the inner caisson is lifted to its final height partly by water pumped into the space between the two caissons and partly by jacks. Then the bottom caisson is filled with sand and gravel.

The telescopic method was used the first time for GRUND-KALLEN lighthouse 1958 and until 1970 in total eight lighthouses of the telescopic caisson type have been built in Sweden. In Fig. 1 the SVENSKA BJÖRN lighthouse in the Baltic outside the Stockholm archipelago is shown. It was placed on its site 1968. It was designed to be manned, but since 1969 the lighthouse is unmanned and supervised per radio. The following data of SVENSKA BJÖRN may be of interest:-

Diameter of bottom caisson		23 m
" " inner "		12 m
" " tower		4.6 m
Height of tower above sea level		32 m
Depth below sea level		13.5 m
Calculated maximum wave height		14 m
" " horizontal wave force		3,800 tons
Assumed maximum ice pressure		4,000 tons
Cost of structure	Sw.Kr.	4,040,000
Cost of equipment	Sw.Kr.	670,000
Total cost	Sw.Kr.	4,710,000

A drawback to the telescopic method is that the bottom caisson which has to provide stability to the caisson set until it is placed on the sea bed has to be rather large, and a large diameter results in high wave forces and ice pressures. Further, a new advanced technique has made it possible to have many of the offshore lighthouses unmanned and therefore the large diameter of the inner caisson for living quarters is not necessary.

A construction method which has been applied to unmanned lighthouses is to reduce the size of the bottom caisson, and to give the lighthouse sufficient floating stability for towing and sinking at site by means of a temporary circular wall on top of the bottom caisson. 14 lighthouses have been constructed according to this "cofferdam method". (Fig. 7)

One of these is the GUSTAV DALÉN lighthouse, Fig. 2, built 1966-67. The following data may be of interest:-

Diameter of bottom caisson		23	m
" " lower part of tower		7.2	m
" " upper " " "		4.6	m
Height of tower above sea level		25.5	m
Depth below sea level		16	m
Calculated maximum wave height		13	m
Calculated " horizontal wave force		2,450	tons
Cost of construction ashore	Sw.Kr.	1,400,000	
Cost " " at sea	Sw.Kr.	1,050,000	
Cost " equipment	Sw.Kr.	750,000	
		3,200,000	
Cost of temporary wall which, however, is re-used several times	Sw.Kr.	600,000	

The construction at sea consists of the preparation of the sea bed by blasting the rocky sea bed and then covering it with a layer of crushed stones, smoothly levelled, towing and sinking of the lighthouse, removing the temporary wall, stone filling around the bottom caisson, sand filling, covering the sand fill with concrete, cement grouting of the foundation bed etc. Mapping and general planning are not included in the costs.

The lighthouse is provided with a helicopter landing platform on top of the tower. Sleeping accomodation is provided for temporary visitors, although the lighthouse operates unmanned.

Wave action

Wave heights and wave periods in front of a lighthouse site are determined by means of calculations based on wind velocity, fetch and depth, taking also diffraction and refraction into consideration. The maximum wave height is assumed to be about 1.8 times the significant wave height. Sometimes also waves still larger than the calculated one have been tested.

Several hydraulic model tests have been carried out in order to determine wave forces, and wave run up and spray for various lighthouse structures, sea bed conditions and wave dimensions[4,5].

For a large depth at the site the highest wave will be the most dangerous wave but for a smaller depth the highest wave will break a distance ahead of the lighthouse and lose energy before it reaches the lighthouse. In such cases lower waves which begin to break just ahead of the wall of the lighthouse will create the largest wave pressures. For some of the lighthouses the wave forces were not determined by means of model tests but calculated on the basis of other model tests on similar sites and wave conditions.

Wave run up and spray will be troublesome especially in winter when ice cover on the tower may result. The model tests have shown that a balcony around the tower will throw the uprushing water out into the sea again, thus lessening the risk of ice cover on the higher part of the tower.

The model tests were carried out at the Hydraulics Laboratory of the Royal Institute of Technology. One of the wave flumes used for the tests has a width of 1.2 m and a water depth of 0.6 m and another has a width of 3 m and a water depth of 1.2 m.

At the lighthouse ÖLANDS SÖDRA GRUND wave pressure measurements were made[2]. Pressure cells placed along the bottom of the lighthouse showed that the uplift pressure varied practically linearly from the water pressure at the windward side to the water pressure at the leeward side, and that the uplift pressures kept time with the waves. During these measurements the bed of crushed stone on which the lighthouse was placed was still not cement grouted. Good agreement between measured wave pressures at the site and in the laboratory was obtained. However, the pressures in the model were sometimes 10 - 20 % higher than at the site. The reason might be that the waves in the model were sinusoidal but at the site more steep having less water volume in the peak protion.

Owing to the good agreement between the model tests and the site measurements no further measurements at other lighthouses have been done.

Ice pressure

Ice pressure on a lighthouse may be caused by moving pack-ice, or by a whole ice sheet in which the lighthouse is frozen, or by a moving large ice sheet, which hits the lighthouse. Fig. 3 shows the lighthouse GRUNDKALLEN in moving ice.

For design the magnitude of the ice pressure is assumed to vary from 50 to 100 tons per metre of the diameter of the lighthouse on the west coast of Sweden and up to 150 to 200 tons per metre in the northern Gulf of Botnia. These assumptions are based on estimates and experiences and on model tests on pack ice[1]. No effort has been made to register the ice pressure acting on offshore structures.

As examples of ice pressure observations may be mentioned the failure of a lighthouse, NYGRÅN, in Northern Sweden and the sliding of anoter one, TAINIO, in Finland.

The lighthouse NYGRÅN was constructed in 1958, Fig. 4. It has a bottom caisson, 14 m in diameter, founded on a depth of 5 m. At a depth of one metre a vertical concrete tower, 2.5 m in diameter, was connected to the bottom caisson. The lighthouse was designed for an ice pressure of 375 tons, corresponding to 150 tons per metre, acting 0.5 m above sea level.

During the winter 1968-69 the tower was broken at the connection section between the tower and the caisson and fell down on the ice, Fig. 5. The steel reinforcement bars in the surface of failure showed typical tension failure.

The bending moment at failure was calculated to have been about 800 tm. Observations showed that pack-ice of considerable thickness has slided upwards on the conical surface of the caisson. Tensile cracks in the wall of the tower, 2 m above the surface of failure, show that the pack-ice must have had a considerable thickness. Therefore, it is probable that the centre of attack of the ice pressure on the tower was located higher than assumed. If the pack--ice had a thickness of 6 m, and the ice pressure was horizontal and hydrostatically distributed, the centre of ice pressure would have been about 2.0 m above the surface of failure and the total pressure on the tower 400 tons. At the level 2 m above the surface of failure the bending moment would have been 240 tm and the tensile stresses in the concrete large enough to cause the tensile cracks observed. With these assumptions the ice pressure on the tower amounts to about 400 tons corresponding to about 160 tons per metre of diameter. Horizontal ice pressure must have acted also on the caisson, and the total ice pressure must have been larger than 400 tons, corresponding to an angle of feiction at the sea bed of more than 0.57. However, no sliding of the caisson occurred.

The TAINIO lighthouse in southern Finland has a bottom caisson, 14 m in diameter, and a tower 3.5 m in diameter. It was placed on the prepared sea bed in October 1966. No grouting of the bed of stones was made and some of the concrete and sand fill within the caisson was missing when a strong winter set in. In February 1967 the lighthouse had been pushed away horizontally a distance of 14 m towards SE. The temperature had been very low for several weeks, -10^{o} to -26^{o}C, and then strong wind, 6 Beaufort, from NW gave rise to ice drift. At an inspection a week later the pack-ice on the western side of the lighthouse had a thickness of 3.5 to 4 m, the upper surface being 0.5 m above water level. Farther away from the lighthouse the ice sheet of black ice had a thickness of 0.65 m. The weight of the lighthouse in water was calculated to have been 780 tons. The friction coefficient between the bed and the concrete bottom of the caisson is not known. Tests have shown values of about 0.56 between a concrete surface and ungrouted crushed stones but also as low value as 0.3 when the lighthouse partly rests on levelling steel girders. Thus, the horizontal force may have had a value of between 233 and 436 tons, the lower value corresponding to 67 tons per metre of the diameter of the cylindrical tower and the higher value to 125 tons per metre.

Erosion

Most of the lighthouses have been placed on rock or rocky moraine. After grouting of the bed of crushed stones there has not been any erosion problem.

Lighthouses on soft foundation have got an erosion protection of stones and boulders around the foundation. The stones and boulders should be large so as to withstand the flow velocities when the waves are passing the lighthouse. Soil investigations are made in order to determine the bearing capacity of the soil and be sure that the variations of pressure between the bottom of the caisson and the foundation for passing waves will not result in settlements of the lighthouse.

In the near future the lighthouse FALSTERBOREV will be erected on a sandbank in the southern Baltic on a depth of 18 m. Extensive model tests of two alternative locations having depths of 12 and 18 m were studied. The largest significant wave height at the latter location at heavy storms was calculated to be 4-5 m and the period 9.5 sec. The model tests were performed for different types of waves having heights up to 9.5 m at 18 m of depth and periods up to 13.5 sec. Flow velocities of 1 knot have been measured at the lightship near the bank and were also reproduced in the model. The tests showed that the structure should preferably have a low bottom caisson and a tower of a rather small diameter, thus being a small obstacle to the waves and flow, and causing small flow concentrations near the bottom outside the caisson. An erosion protection at 18 m depth required less stone sizes than at 12 m depth. The long time effect of the littoral drift together with waves and flow was studied using plastic sand. If the erosion protection of boulders having an appropriate size would extend well outside the caisson no erosion on the sea bottom around the lighthouse except on a small spot behind the lighthouse outside of the erosion protection was observed in the model tests, Fig. 6.

References

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Figures

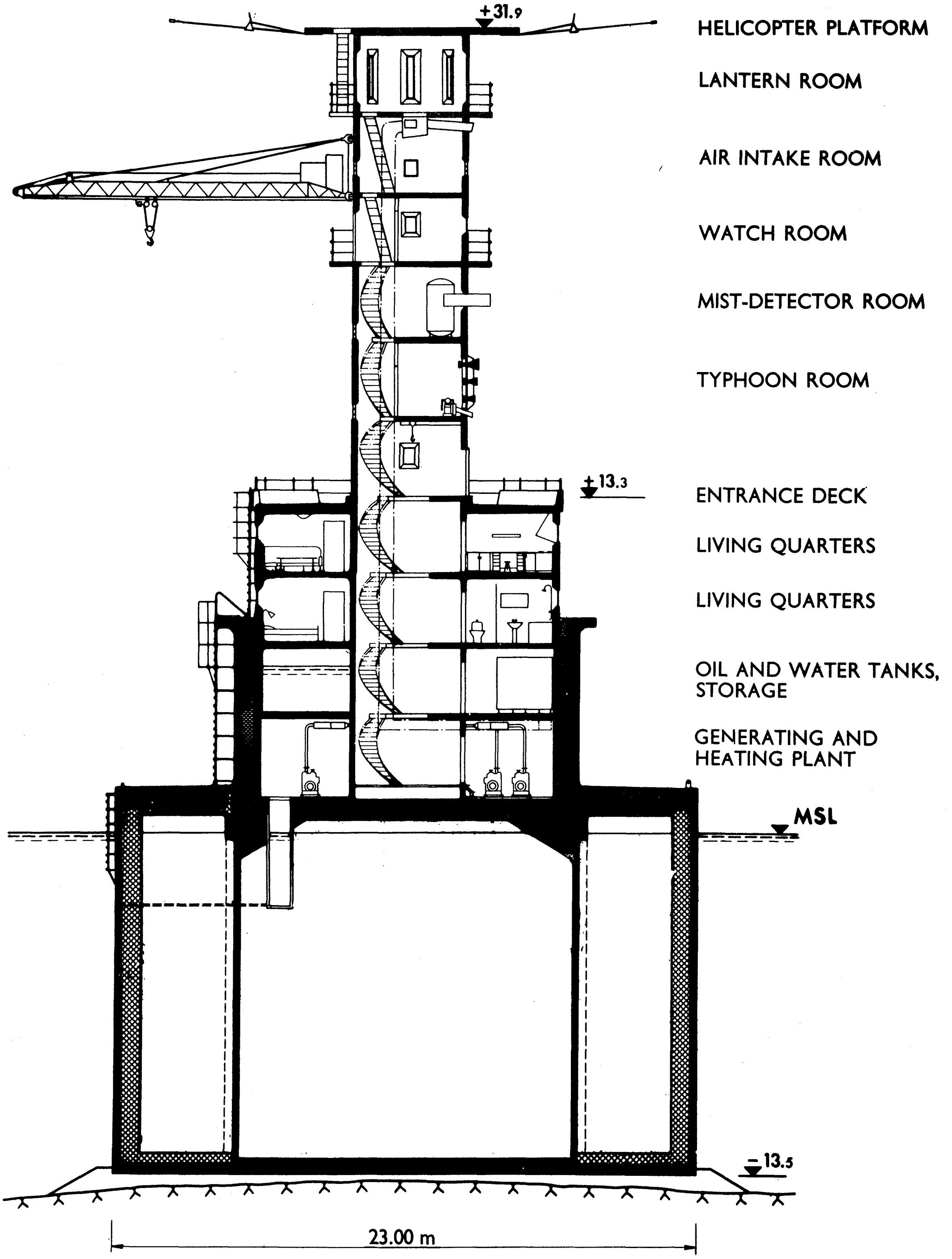

+31.9
HELICOPTER PLATFORM
LANTERN ROOM
AIR INTAKE ROOM
WATCH ROOM
MIST-DETECTOR ROOM
TYPHOON ROOM
+13.3
ENTRANCE DECK
LIVING QUARTERS
LIVING QUARTERS
OIL AND WATER TANKS, STORAGE
GENERATING AND HEATING PLANT
MSL
-13.5
23.00 m

Fig.1

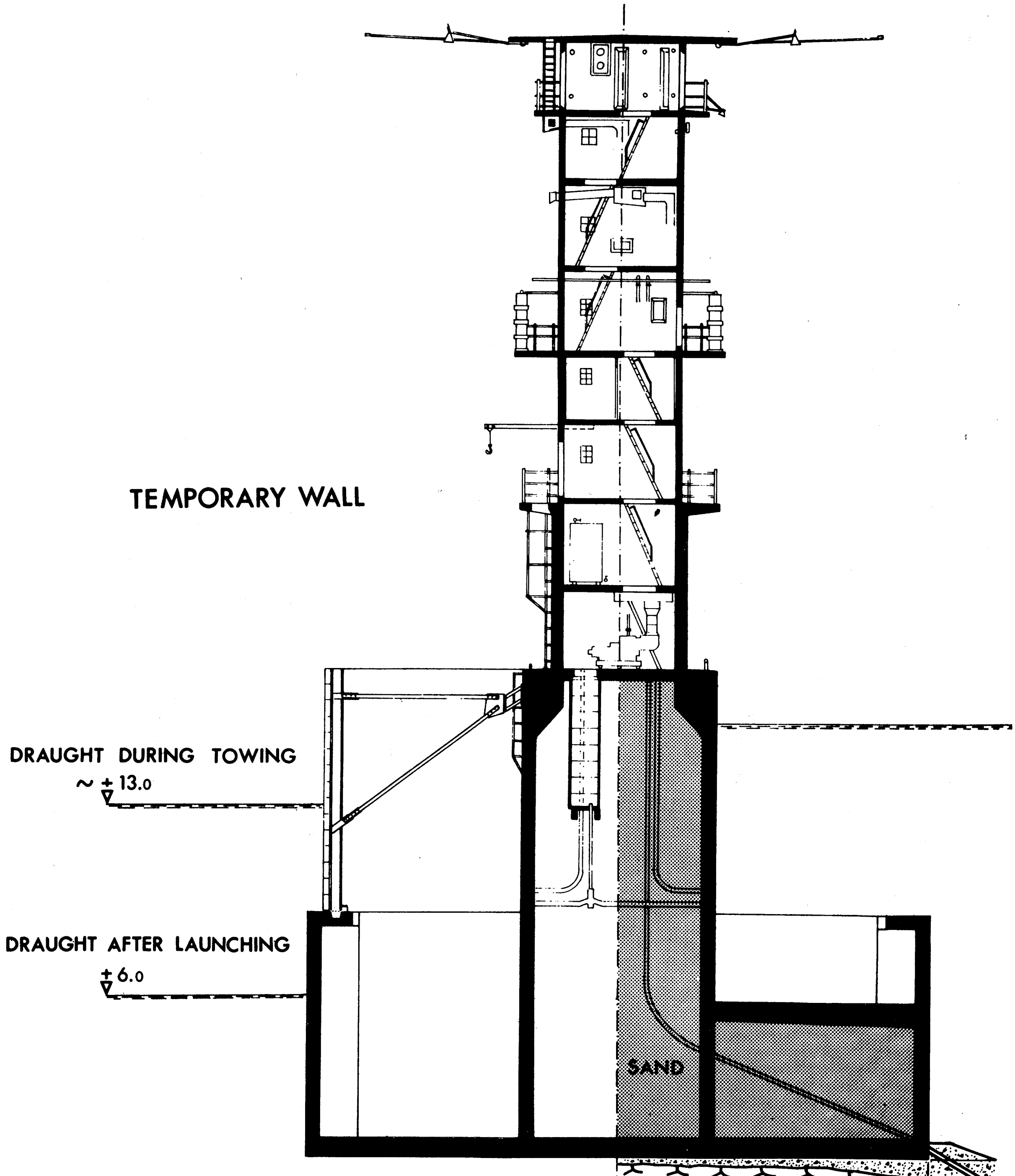

TEMPORARY WALL
DRAUGHT DURING TOWING
~ + 13.0
DRAUGHT AFTER LAUNCHING
+ 6.0
SAND

Fig.2

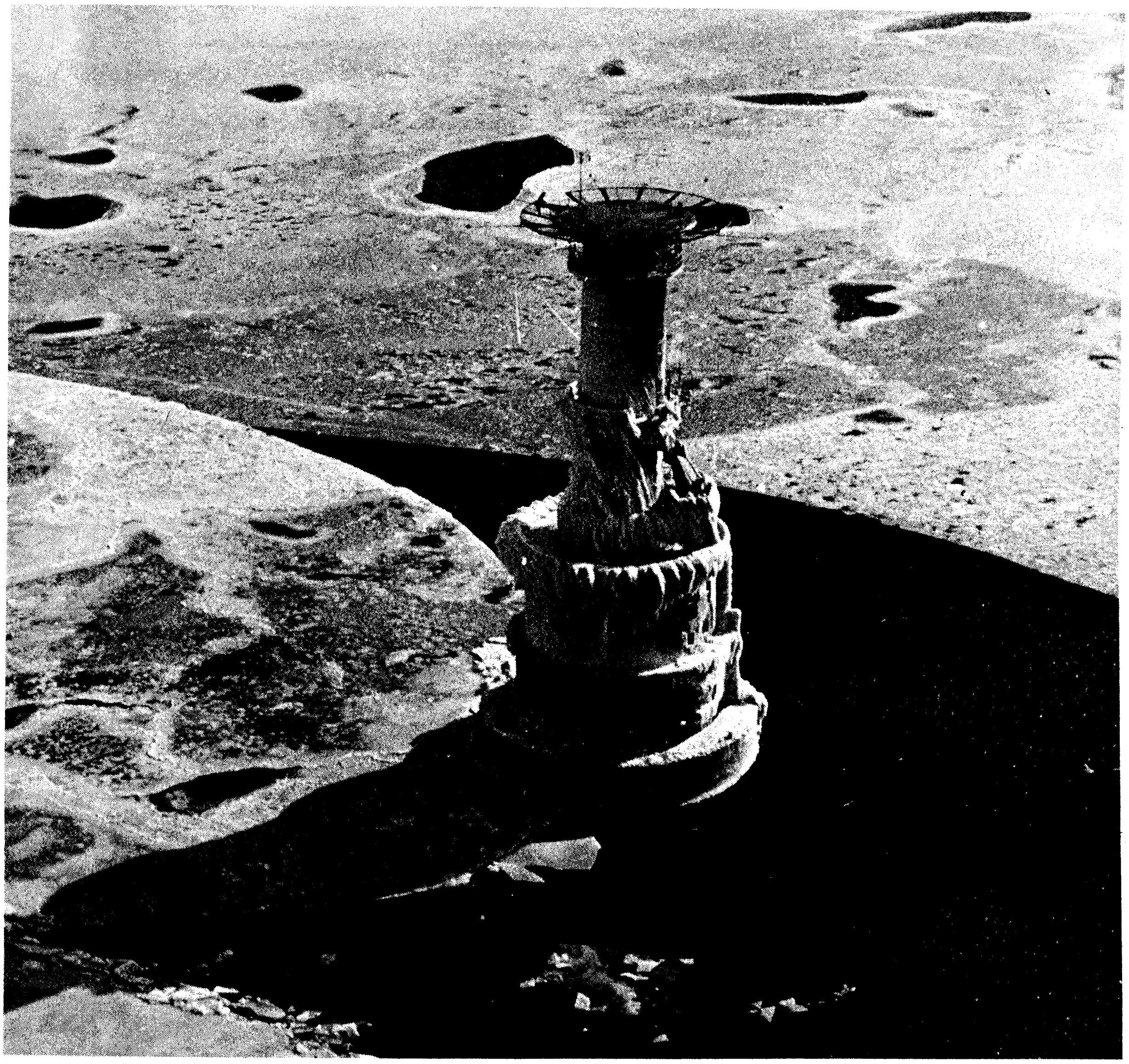
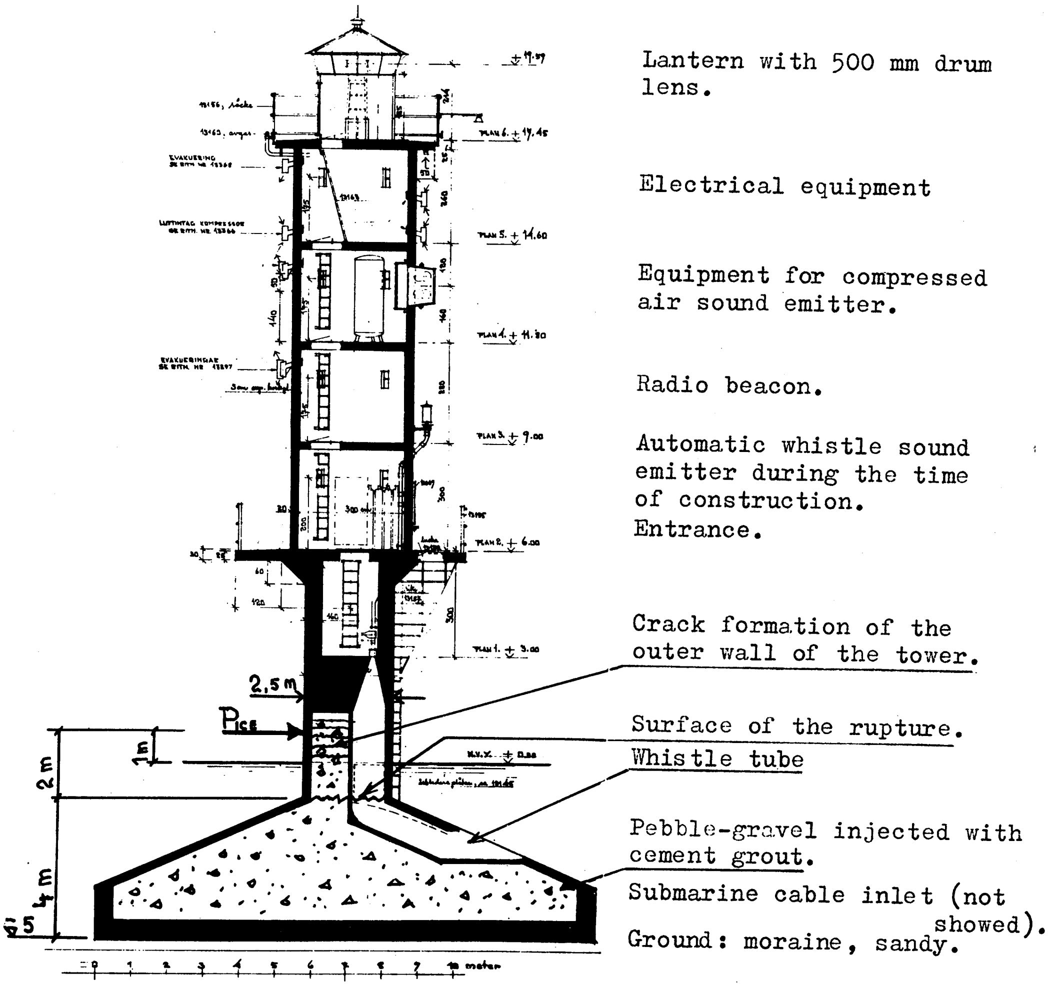


Fig. 3



THE NYGRÅN LIGHTHOUSE

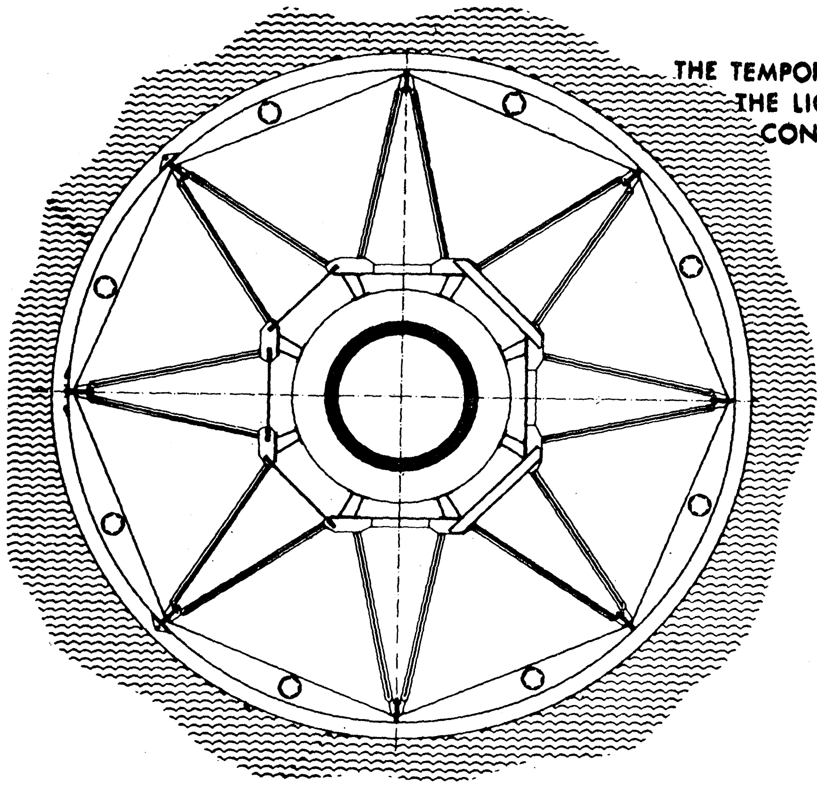
Fig. 4

Fig. 5

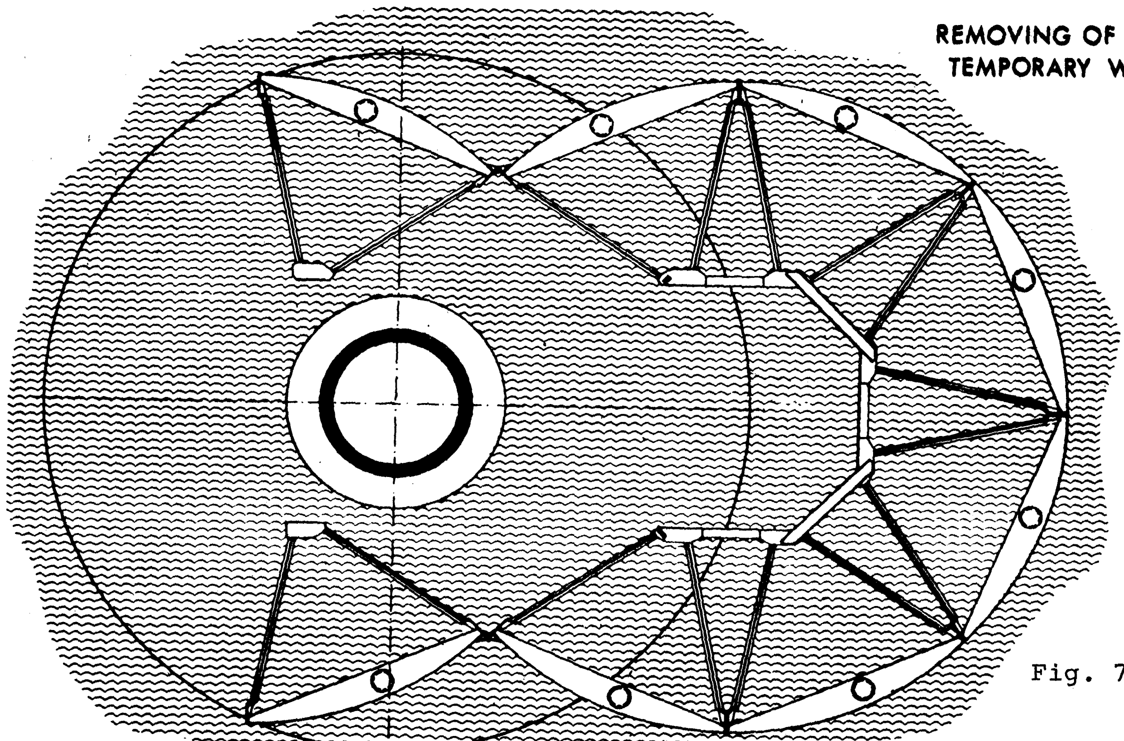
Fig. 6

THE LIGHTHOUSE GUSTAF DALÉN

CAISSON WITH TEMPORARY WALL



THE TEMPORARY WALL MOUNTED ON THE LIGHTHOUSE CAISSON AND CONNECTED TO THE TOWER



REMOVING OF THE TEMPORARY WALL

Fig. 7