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Hurtigruten Museum – protective building for M/S Finnmarken

Structural design and engineering

M/S Finnmarken (1956) was part of the traditional fleet named "Hurtigruten" operating along the Norwegian coastline for centuries. Finnmarken is named after the Northernmost region of Norway, Finnmark, sailing during the years 1956–1993. Historically, "Hurtigruten" represented the major element of logistics for the coastal society in Norway for decades, transporting goods and personnel between Bergen on the west coast, to Kirkenes at the northernmost and eastern location of Norway. In modern times, the fleet also has become a popular cruise line for tourists, offering spectacular views to fjords and coastline of Norway. Thus, "Hurtigruten" indeed represents an important part of the Norwegian history. In this respect, The Protective Building Project aims to be part of the documentation of this history, exhibiting one of the traditional ships, docked and built into the most important part of the museum.
The museum consists of three buildings: The new *Protective Building* around the ship, the existing *Triangular Building*, and the new *Steamboat Building* housing an extant and authentic section from the oldest ship D/S Finnmarken that operated in a period from 1912. The *Protective Building* is designed as a massive shell around the ship with a height of nearly 21 m, a width of nearly 20 m and a length of almost 100 m. It is exposed to a wind peak velocity of v_p = 49.44 m/s, designed with a flexible structure being able to deflect acceptably with respect to the other buildings. The museum is located by the sea front, being highly exposed to a marine environment.
The conceptual design phase started up in 2015, in developing the architectural approach based on visions of the client. The steel structure represents a key element of the architectural design. Thus, the structural design was part of the concept phase. The contractor started erection of the structures in 2019, and the official opening took place on the 28th August 2021, where the Norwegian Minister of Cultural Affairs officially opened the museum for visitors.

1 Design development

The client's vision was to establish a landmark, placed in its cultivated landscape representing the history, with an

Fig. 1 Hurtigruten museum in northern light

Fig. 2 Protective Building towards the sea, in front of the Steamboat Building to the left and the Triangular Building to the right.

open view to the sea and “Hurtigruten’s” sailing route. The lightning, with its specially designed features, exposes the ship and the building structure, creating a spectacular image also during the dark polar night. Exposure and visibility are essential also during days with constant daylight and midnight sun, in contrast to the harsh arctic snowstorms during wintertime.

The *Protective Building* is the larger part of the museum, surrounding M/S Finnmarken. The *Triangular Building* is the old part of the museum with reception, public areas and a new technical room built on top of the existing concrete structure. A saloon deck from the oldest ship D/S Finnmarken that operated in a period from 1912, is placed in the *Steamboat Building*, designed to fit around the section. All three buildings are connected such that walking through the exhibitions feels like moving in one building.

1.1 Architectural inspiration

When designing the building LINK Architecture wanted a storytelling connection between the ship and the building. The shape of the building is inspired by the ships slanted shape on each side: M/S Finnmarken was the first ship where the openings of the ship sides had a slanted shape, giving the impression of a ship moving speedily forward. A white frame defines the buildings shape, with white metal fittings around the edge and next to the glass wall.

1.2 Loads and environment

Basis for the design of the structures is the Eurocode EN 1990, EN 1991, EN 1992, EN 1993, EN 1997 and EN 1998. The location is exposed to arctic climate with heavy snow fall, drifting snow and high wind loads. The large roof area is designed for considerable snow actions and wind forces, the face of the building resulting in a large wind drag making the global stability a key challenge in the design. The Characteristic value of snow on the ground for Stokmarknes is s_k = 4.0 kN/m^2 in accordance with NS-EN 1991-1-3, and the wind peak velocity is v_p = 49.44 m/s in accordance with NS-EN 1991-1-4.

The building has also been given a robust design, counting for a change in climate in particular sea level rise and possible surges. Wave effects to the storm surge level is considered by analysing the museum’s location and orientation to open sea. The wave sector is protected by the island Børøya on the east of the museum’s location.

1.3 Materials

All foundations are constructed by use of reinforced concrete with dimensions and detailing to obtain a robust and durable design regarding the surrounding environment. Both the foundations for the ship, and those of the *Protective Building* are placed on a filling in sea such that all the concrete structures and floors below a certain level are waterproof. Strong composite steel and concrete structures were necessary to transfer loads from the steel structure and the foundations to the ground.

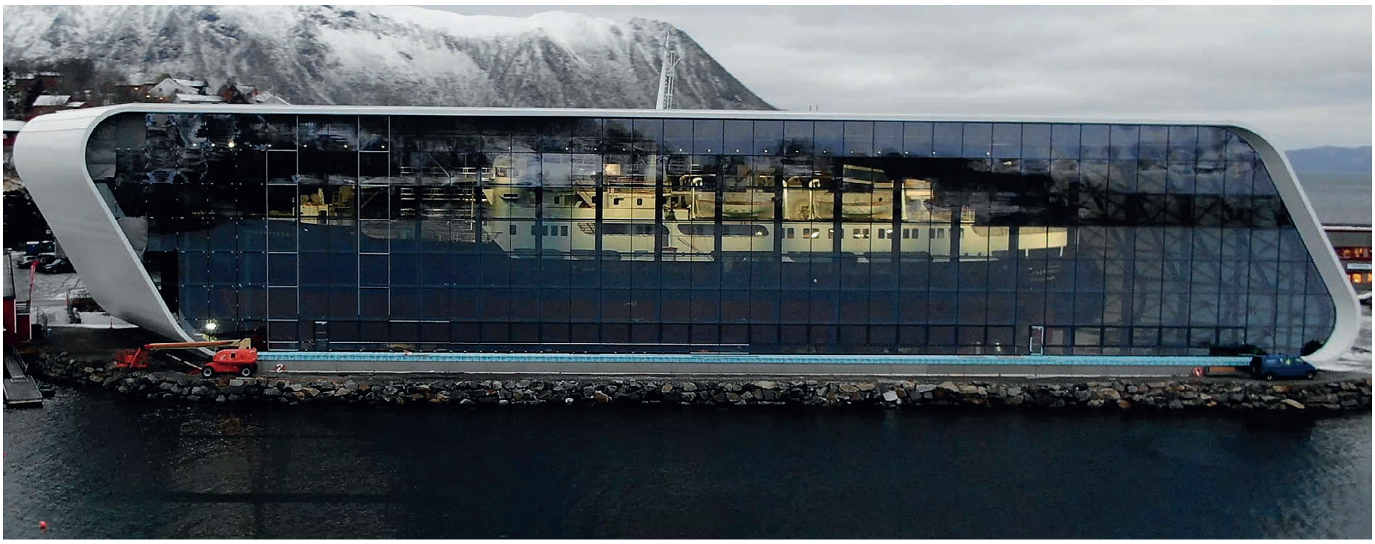


Fig. 3 Architectural inspiration

M/S Finnmarken (1956) is nearly 81 m long, 13 m wide, and around 15 m from keel to the top of the steer house. The *Protective Building* is built as a shell, with a considerable volume around the ship. Structural materials with high strength and stiffness were required for the construction of the superstructure. In this respect, the use of steel as the main structural material was obvious to obtain a sufficiently slender structure with an open sea view without bracings in the glass facade.

2 Global stability

All three buildings have separate structural systems. The *Protective Building* is designed with a flexible steel structure allowing larger deflections compared to the other two buildings.

2.1 Triangular Building

The *Triangular Building* is a concrete building from early 2000. A technical floor is built on top to serve the other two new buildings. The new structure on the top floor is made with steel beams and steel columns fixed to the concrete for reduced weight and slender structures. Bracings of flat steel are placed in all outside walls.

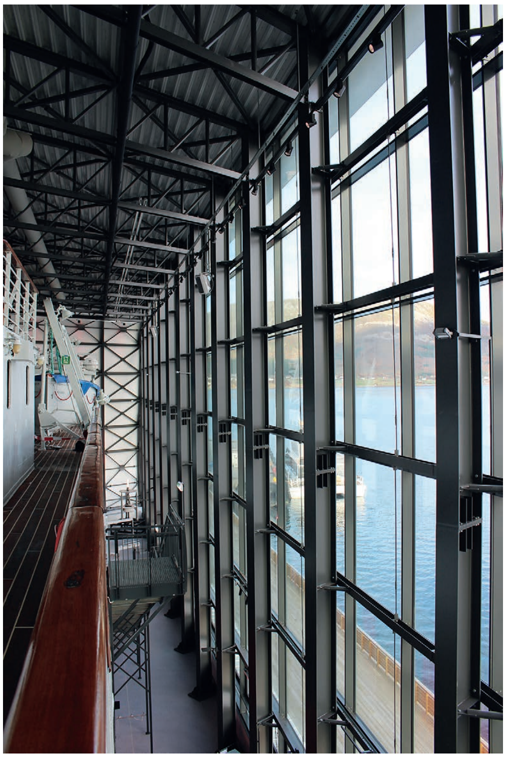


Photo: Multiconsult. © Stian Johansen

Fig. 4 Equally stacked steel frames in the glass façade inside the Protective Building

2.2 Steamboat Building

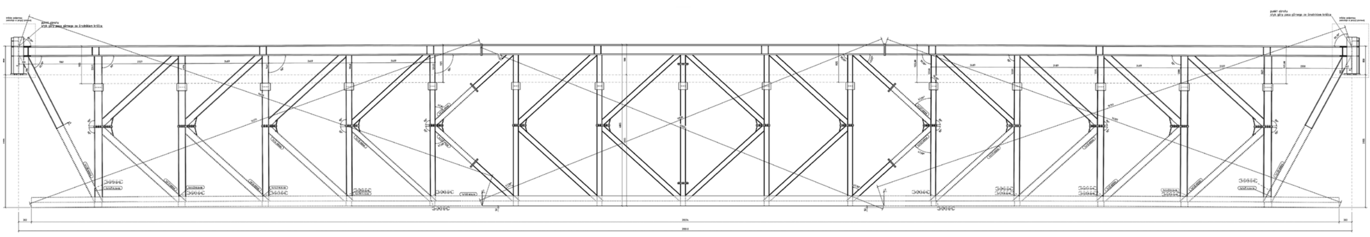
The structural system of the *Steamboat Building* is designed with steel frames bearing the second floor of hollow core slabs. Bracings of steel hollow profile are placed in all outside walls. The old saloon deck from D/S Finnmarken is fixed on top of the hollow core slabs with a steel frame.

2.3 Protective Building

The steel structure of the *Protective Building* is designed as a shell around the ship and counts a height of nearly 21 m, a width of nearly 20 m and a length of almost 100 m. Equal steel frames with columns and roof trusses are stacked in the longitudinal direction with a centre distance of 5 m. This appeared to be the optimal centre distance due to the dimensions of the columns in the glass façade.

As can be seen from the sea view, there is no wall bracing in the glass façade along its own axis. All bracings are placed in both gable walls and in the longer wall pointed landward. These three axes of wall bracing are sufficient for stability in plane, and they are all connected to the roof built as a stiffening diaphragm with crossing hollow profiles at the entire roof plane. Wind forces in each of the steel frames are transferred to the roof diaphragm which distributes forces to the connected wall bracings. To increase the overall stiffness of the building, all steel frames are built as rigid frames with column footings that are rotationally fixed to the concrete foundation.

The positions of the steel columns in the façade pointed landward correspond to the positions of the existing concrete columns of the *Triangular Building*. The existing concrete columns were not designed for the magnitude of dead load and snow load from the trusses over the ship, neither to handle wind loads from each of the steel frames bearing the glass facade. Therefore, it was necessary to construct a large truss in the entire height of the new technical floor to distribute the dead load of the roof and the snow load to each side of the existing *Triangular Building*. This truss has a span width of 39.84 m and a height of 3.955 m. It is constructed to resist a snow load induced from an area of nearly 450 m^2. Two steel columns on each side of the *Triangular Building* are bearing this truss.



Drawing: PPKBHM. © IMTAS/ PPKBHM

Fig. 5 Truss drawing

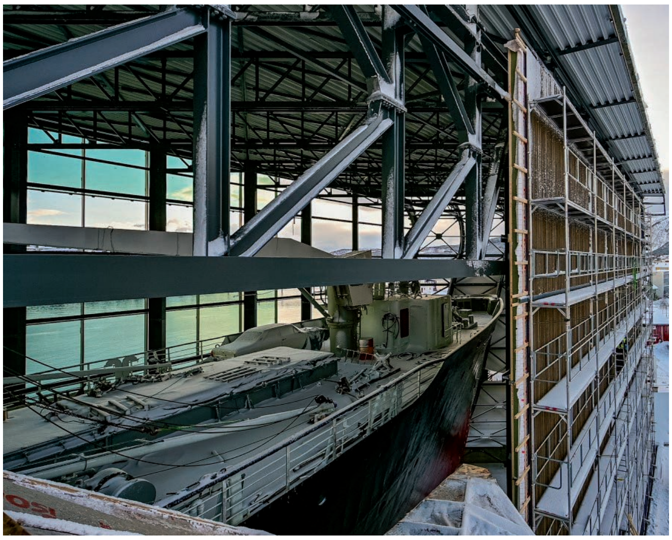


Photo: Peab Bjørn Bygg. © Ørjan Marakatt Bertelsen

Fig. 6 The large truss in the Protective Building designed for deflection over the Triangular Building

When the flexible steel structure is exposed to wind load on the glass façade, the entire structure deflects with a maximum of 70 mm at the middle of the roof span. This means that the large truss is moving over the existing building, and all structural elements including facades and technical infrastructure are designed to follow these movements. Steel columns on top of the concrete columns are designed with footings of cantilevers to avoid collisions with the large truss.

3 Steel design

The steel structure and its total deflection was designed by using a FE-model of the structure of the *Protective Building*.

3.1 Steel frames

A system of trusses for bearing the roof was chosen due to the span width and the significant snow load on the roof. All the steel frames are rotated 60 degrees in plane relative to the axis of the glass façade, which results in a span width of nearly 23 m for the roof trusses. The height of the roof trusses is nearly 1.5 m. They are built up with top- and bottom chords of HE-profiles and bars of circular steel profiles.

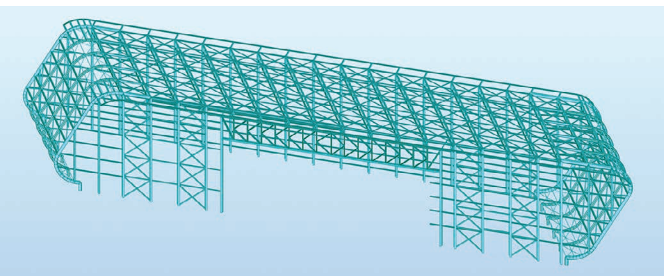


Photo: PPKBHM. © IMTAS/ PPKBHM

Fig. 7 FE-model of the Protective Building

Various types of column profiles were initially discussed in the phase of developing the structural steel system. A system of tapered truss columns in combination with roof trusses was an early alternative because of the possibility to achieve high stiffness by use of more slender truss profiles. Such frames would satisfy the limited deformation criterion for the glass façade, but these types of frames were space-requiring inside the museum around the ship. Because more compact columns met the same criterion for strength and stiffness in combination with the stiffness of the roof diaphragm, these types of profiles were chosen for the steel frames. Column profiles are HE 650 B. All column footings are rotationally fixed to the concrete foundation in order to increase the overall frame stiffness.

The rotation of the columns in relation to the direction of the wind pressure initiates a force along the axis of the glass façade. The lack of bracings in this façade is compensated by horizontal beams to resist the rotation of the columns. The forces are transferred to the foundations through the gable beams at both ends of the steel structure.

3.2 Gable profiles

Gables walls at both ends of the building are essential to the architectonic expression of the museum, and they are important for wall stabilisation of the steel structure. Initially, it was an idea to build up the entire gable walls using thin steel plates with welded stiffeners and flanges

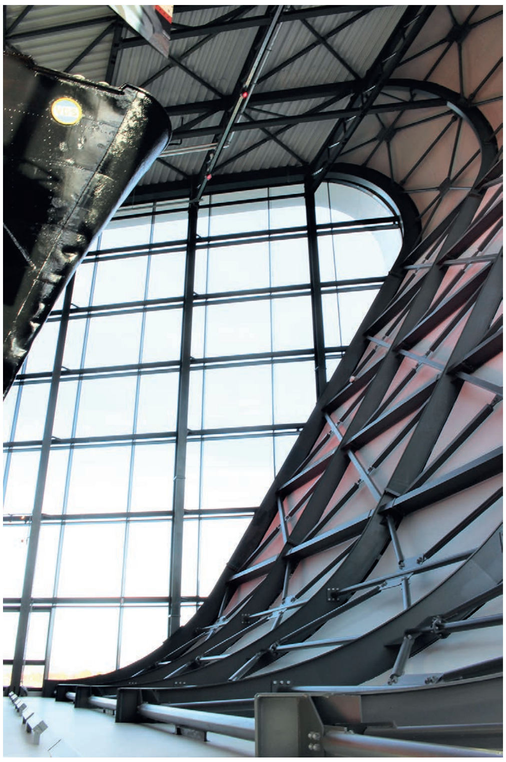


Photo: Multiconsult. © Stian Johansen

Fig. 8 Gable at the south

for vertical bearing and resistance against shear buckling. This would appear as the hull of a ship, but the total weight and cost of this structure was unrealistic for this purpose. A system of six separate profiled gable beams and bracing made of hollow profiles in the entire gable walls was more rational to obtain an optimum of cost, strength, and stiffness.

The curved profile of the gable at the south end is built with an overhang of more than 10 m, bearing snow and dead loads from the roof. This introduces large moments in the gable profile, and the two outermost profiles are in addition resisting the rotation of the steel frame columns exposed to wind load. The four out of six gable profiles in centre are curved profiles of IPE 450, and the two outermost gable beams are curved I formed profiles with double web and a height of 550 mm.

Photo: Peab Bjørn Bygg. © Mats-Andre Hansen Bæhr

Fig. 10 Installation of truss over the Triangular Building

In order to transfer the large moments to the ground, the foundations are designed as a composite steel and concrete structure with steel beams casted into the concrete foundation.

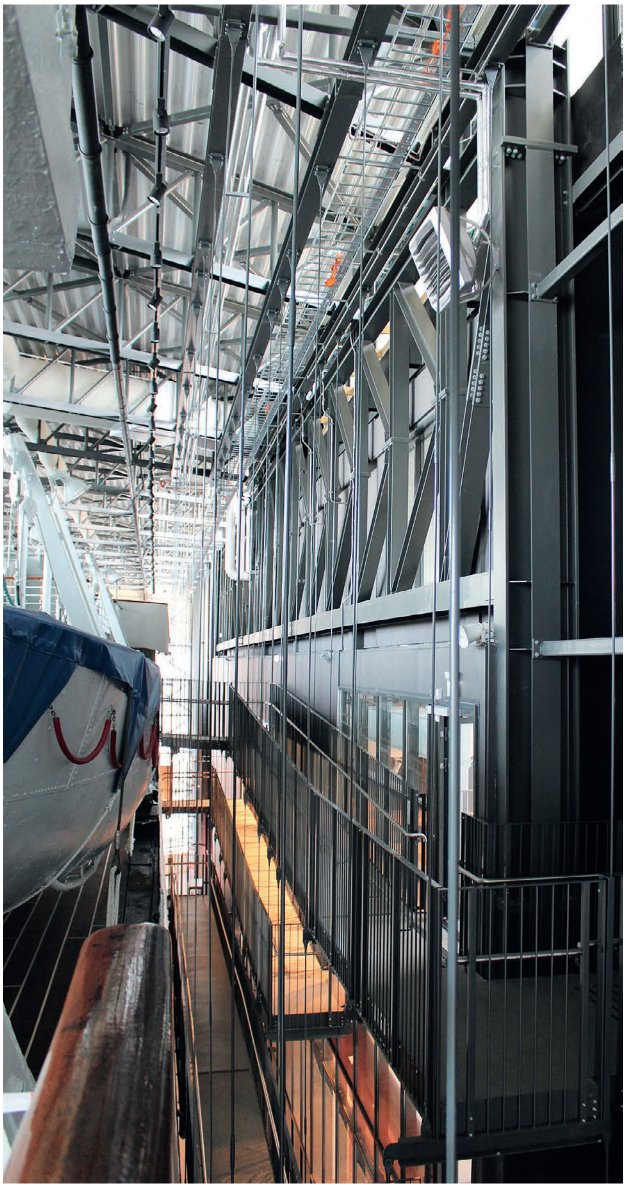


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Fig. 9 Visitors can enter the ship from suspension ramp hanging in tension cables from the roof trusses

3.3 Connections

All the steel components are welded together at the factory, transported to site, and bolted together. Connecting components mounted on site are bolted connections.

3.4 Fire resistance

Validations of fire scenarios are performed, considering accidental load situations with fire inside the *Protective Building*. This study resulted in the implementation of a ventilation system including automatic openings in the lower glass façade in combination with openings underneath the roof at the other side. Ventilation of the volume reduces the gas temperature and the amount of fire gasses during fire inside the *Protective Building* significantly. Thus the steel structure is designed to meet the standard fire criterion R15/A2-s1,d0.

3.5 Ship entrance from ramps

Entrances to the ship are located several meters above the ground floor in the museum. Visitors can enter the ship from three levels of suspension ramps, entered from the elevator shaft and the floors of the *Triangular Building* and *Steamboat Building*. Platforms are constructed using thin plate steel cassettes filled with concrete, hanging in tension cables from the roof trusses and horizontally fixed to the nearby structures of the building.

4 Construction phase

All steel components were transported to site in sizes in accordance with normal transport criteria. If necessary, structural components were bolted together on the ground before installation. The large truss over the *Triangular*

Building was mounted in its total height and span width by the use of two separate lifting cranes in a coordinated lifting operation. Gable profiles were also installed using two separate lifting cranes.

Data block

Client: Vernebygg AS, Norway
Architect: LINK Arkitektur, Norway
Engineering group, structural design: Multiconsult, Norway
PPKBHM, Poznan, Poland
Contractor: Peab Bjørn Bygg, Norway
Contractor steel: IMTAS, Norway

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