PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

YEAR-ROUND OIL TERMINAL IN ICE COVERED WATERS

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On the south shore of the St. Lawrence River at St. David de Levis, Quebec, a new refinery has been completed for Golden Eagle Canada Limited. This refinery has a scheduled production of 100,000 barrels per day. An integral part of the refinery is the new marine terminal designed to receive crude oil tankers ranging in size from 65,000 D.W.T. to 100,000 D.W.T. and to provide terminal facilities for shipping refined products in vessels ranging from 2,500 D.W.T. to 20,000 D.W.T. Minimum water depths at normal low tide are 55 feet (16.8m) and 32 feet (9.8m) respectively.

This wharf is subjected to severe ice action and is designed to operate on a year-round basis.

It was established that the structure must be designed to absorb the impact of very large ice floes. To protect the large tankers moored at the outer berth from damage by large ice floes, ice breaker cells have been placed upstream from the berth, and the alignment of the wharf has been selected so as to provide protection to the stern of these vessels when ice floes move up-river on the flood tide.

This leaves collisions by wind driven ice floes as the main danger to the wharf and to the vessels. The wharf is designed to resist impact. Ice action is mitigated by a fender system, which consists of large rubber pneumatic fenders designed to permit the vessel to yield several feet if struck by a glancing blow from large ice floes.

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On 7 July 1971 a tanker brought crude oil for the first time to the Golden Eagle refinery on the South Shore of the St. Lawrence at St. David de Levis, Quebec. The wharf, shown on figures 1 and 2, had been however constructed in the previous year and was under observation during the winter of 1970-71, prior to its being put into service. Since the wharf structure had been completed before this winter, its ability to withstand St.Lawrence River ice is indicative of its expected performance in the future. Winter conditions are illustrated on figure 3.

The berths at the wharf were cleared of ice on a trial basis during the 1970-71 winter by an icebreaker in a manner likely to be used when in full operation in the future, as shown on figure 4.

Thus a wharf has been commissioned to supply crude oil to a refinery both in summer and in winter, including periods when the St. Lawrence River is covered with ice.

PERFORMANCE REQUIREMENTS

The possibility of oil production in northern seas has created a strong interest in marine terminals designed to operate in ice covered waters, where open sea may be rare or non-existent. In seas which are open for part of the year, cost considerations still favour year-round teminals because of the very high cost of oil storage.

Similar economic considerations may even apply to crude oil terminals for refineries in the north. The Golden Eagle refinery has a scheduled production of 100,000 barrels per day. There are 12 tanks each with a capacity of 500,000 barrels for crude and residual fuels.

This terminal has been designed to receive crude oil tankers ranging in size from 65,000 D.W.T. to 100,000 D.W.T. and to provide terminal facilities for shipping refined products in vessels ranging from 2,500 D.W.T. to 20,000 D.W.T. Berthing structures are depicted on figures 1 and 2.

Design vessel characteristics:

	Berth No. 1	Berth No. 2
Maximum size:		
Length	900 feet	544 feet
Beam	146 feet	74 feet
Draft loaded	48 feet	30 feet
Dead weight tonnage	100,000 tons	20,000 tons

DESIGN CRITERIA

Water depth

Minimum water depths at normal low tide are to be 55 feet (16.8m) and 32 (9.8m) respectively, for berths nos. 1 and 2 and their approaches, as shown on figure 2.

There is a spring tidal variation of 20 ft (6.1m). At normal high water level the depth of water at the outer berth would be 73.5 ft (22.4m).

Wharf design criteria for summer season

Environmental and climatic analyses were carried out to determine the interaction of ice movement, current flows and wind. At the proposed site, tidal variations in water level of 20 feet (6.1m) and reversing river currents of 7 feet per second (2.1m/sec) required detailed hydraulic studies of scour effects and navigation problems in the vicinity of the berthing area.

The National Building Code of Canada designates the entire St. Lawrence Valley as a zone of major seismic disturbances, the immediate vicinity of Quebec being criss-crossed by a number of faults. These facts have been taken into consideration in the design of the gravity structures. Earthquake effects have been considered in design by applying a horizontal earthquake force acting on the dolphins. The design force has been estimated at 5,000 tons applied approximately 45 feet (13.7m) above the base.

The berthing velocity perpendicular to the wharf face of 100,000 D.W.T. vessels was assumed to be 0.5 feet per second (0.15m/sec). The kinetic energy arising from the impact of berthing at this speed would be absorbed by fenders.

Ice criteria for structure

The marine terminal is located in a region with severe ice conditions every winter, as indicated on figures 3 and 4.

The structural design of the wharf is based on extreme conditions which have been considered possible on rare occasions.

Consolidated ice thickness has been assumed to be 4 ft (122cm). This presumes some deformation and reconsolidation which could occur in extremely cold winters.

The main unconsolidated mass of ice in this part of the river would occur in hanging dams carried downstream as the ice cover breaks up. The maximum thickness of these hanging dams has been estimated at about 60 ft (18.3m). An average equivalent consolidated ice thickness of 15 ft (4.6m) has been used in computations. The total weight of floes which could collide with a structure has been estimated at 700,000 tons.

The maximum current driving the ice floes has been estimated at 7 feet per second (2.1m/sec). Floes carried by this current could collide with the icebreaker cells and possibly with the end dolphin of the wharf. The alignment of icebreaker cells and the wharf has been chosen so that a floe drifting on the river side of the icebreaker dolphins would be carried by the downstream drift past the wharf and any vessel at berth at the wharf face, except when driven across the river by strong cross-winds, which can reach 56 mph (25m/sec) for an hour once in 1000 years. Larger floes colliding with the icebreaker dolphins would be partly broken and partly rotated past the wharf.

There have been ridges observed in the area. Since these ridges have been formed in first year ice and have not been annealed over a second winter, their additional strength would be limited to partial refreezing of the sail while the keel could be assumed to form an unconsolidated mass.

In such ice conditions, an ice thrust of 4800 tons has been considered in the design of the 80 ft (24.5m) diameter substructure cells. For icebreaker dolphins this load is considered to be a frequent occurrence. For the protected berthing dolphins, this thrust is considered an extreme load, and 2800 tons has been taken as a single normal loading.

Ice criteria for operations

It has been assumed that shipping will not use the wharf in extreme ice conditions, but that operations will be restricted to periods of normal severity.

The normal maximum ice sheet thickness in the Quebec region of approximately 30 inches (76 cm) is therefore the main design parameter from which other operational ice criteria have been developed.

Rafting to a thickness of two layers (or for thinner ice, even more) has been observed in the area. However, the layers of rafted ice would not be strongly bonded. Individual point loads would be limited therefore by the thickness of the previously-mentioned ice sheet.

Ships would be affected also by ice clusters formed on the shores in the ice foot region. In the area of the wharf they have been observed to reach 10 ft (3m) in diameter. Such balls would however be of lesser strength than sheet ice.

There is no practical way of avoiding collisions between a ship and ice floes while strong winds are blowing across the river. The rapid process of spalling splitting of ice masses compared to the slow motion of the ship makes it even difficult to alleviate the magnitude of instantaneous point loads caused by the ice floe and these may reach 200 tons. Therefore ice floes driven southward by wind and colliding with ships and the wharf must be considered.

PLANNING FOR WINTER CONDITIONS

The site of the marine terminal has a history of severe ice conditions which cannot be avoided if winter operations are undertaken.

Overall economic considerations indicated that shipping berths should be located just outside the limits of shorefast ice along the south bank fo the St. Lawrence River, as shown on figure 1. The location has some advantages, such as the accessibility to the outer berth by open water navigation during a substantial portion of the winter. On the other hand, mooring facilities and moored ships could be subjected to severe impacts from large ice floes and could be subject to intense pressure from ice fields encircling them.

To determine the feasibility of operating a supertanker wharf on a year-round basis, a detailed study was made of ice conditions along this section of the St. Lawrence River prior to construction. In the winter of 1970-71 ice conditions and ice action on the wharf were also observed under conditions similar to those expected in the future. These studies were carried out with the help of the Canadian Department of Transport icebreakers and observation helicopters.

It has been assumed that in winter the outer and the inner berth would be operated with the help of icebreakers. The possibility of clearing the berths by icebreakers was ascertained by trail icebreaker operations in the winter of 1970-71, as shown on figure 4.

To protect the large tankers moored at the outer berth from damage by large ice floes, carried downstream by the river, icebreaker cells have been placed upstream from the berth, and the alignment of the wharf has been selected so as to provide protection to the stern of these vessels when ice floes move up-river on the flood tide. The layout is illustrated on figures 1 and 3.

Ice floe remnants emerging from between the icebreaker cells are small enough not to cause damage upon impact.

The measures adopted to protect berthed ships in winter do not cover collisions with floes driven across the river by northerly winds. During first impact loads, the ship may be assumed to be stationary, since the inertia of the ship will not allow the ship to react quickly enough to alleviate the impact.

At very low velocities, the transverse momentum of the ice floe would be absorbed by deformations in both the ice and the ship, essentially in the elastic range. No serious damage would occur to the ship.

At higher velocities, the impact energy cannot be absorbed by deformations and plastic moulding only. Ice floes would break whereas the ice balls mentioned previously would be split. Extended ice floes would be spalled vertically. Tankers would be subjected to concentrated forces which are limited to loads required to break ice locally by spalling or splitting.

The impact forces may cause repeated local spalling and a general moulding of the ice floe edge against the ship. This process would continue until the momentum of the floe is spent.

To reduce build up of forces during this process, the ship is laterally supported on a very soft fendering system.

STRUCTURAL DESIGN

Concrete cells, 90 ft (27.5m) high and 80 ft (24.5m) in diameter seated on prepared rock mattresses, form the substructure of the wharf, as shown on figure 2.

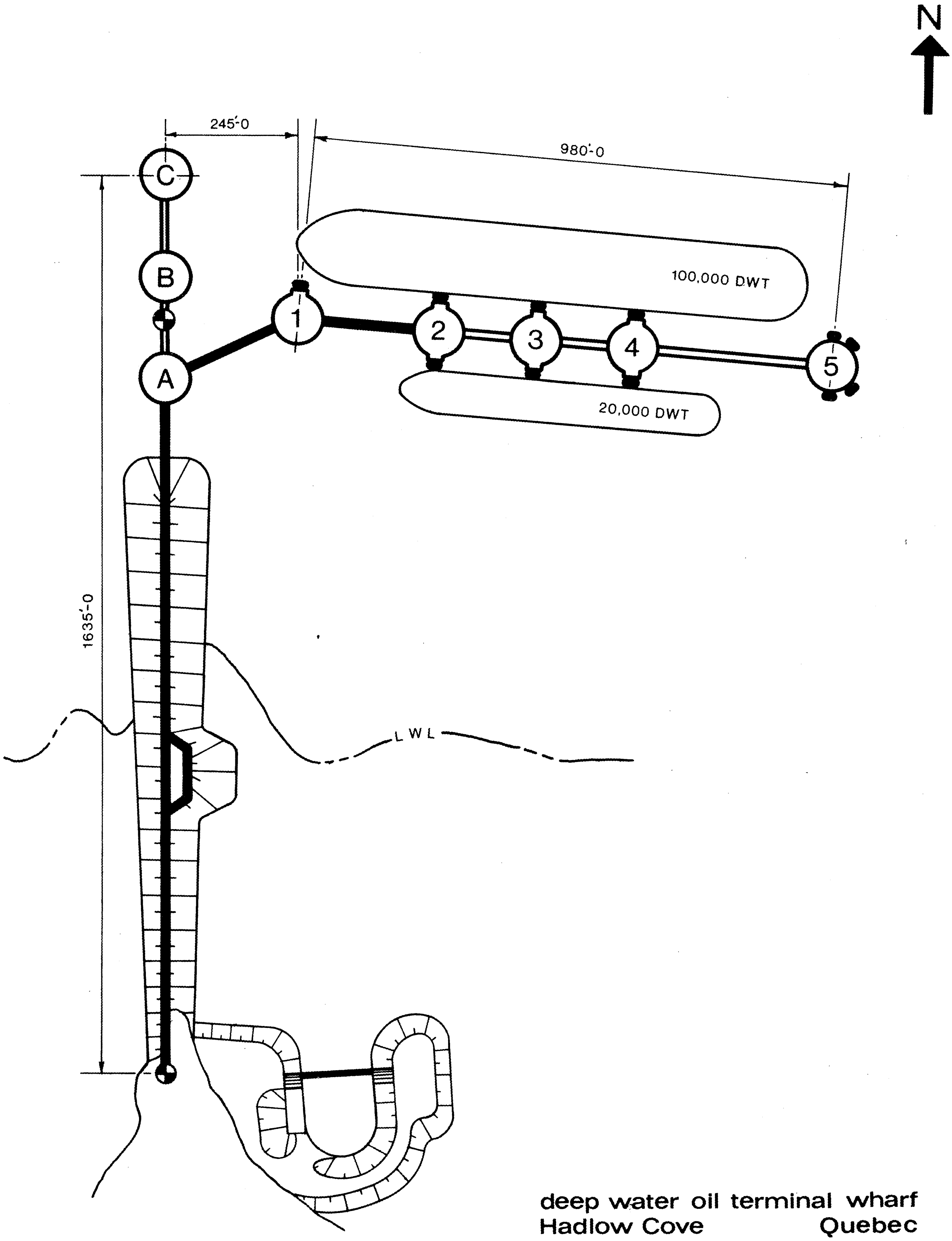
The concrete cells are interconnected by steel bridge trusses carrying a vehicular roadway along the bottom chords and pipelines on the top. A 1,000-foot rockfill causeway leads to the wharf head. The slopes of the causeway are armoured to protect this portion of the structure against ice and wave damage.

CONSTRUCTION

Construction of the wharf facilities took place during 1970 with the concrete cells being partially poured in a building basin designed and constructed specifically for this purpose. The cell units were built approximately 15 ft (4.6m) high, the basin was then flooded and the units towed and anchored in their final position. A three point anchorage system was designed to secure the cells and to withstand forces acting on the cells caused by reversing river currents. The cells were completed by sliding forms utilizing marine plant to convey concrete to the structures.

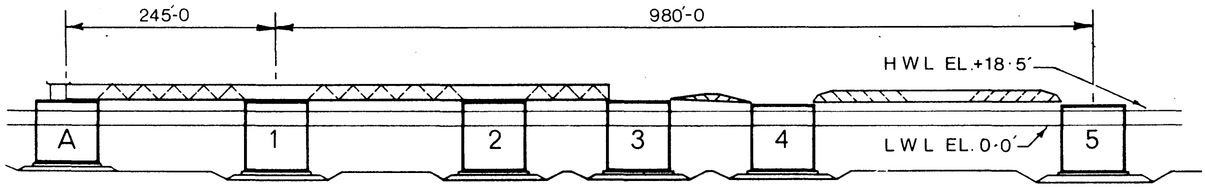
The steel trusses were fabricated onshore, and the tide was utilized to float the completed trusses by barge into position. On the falling tide, they were set on to their bearings.

The total elapsed time for the design and effective completion of construction of this project was 16 months.

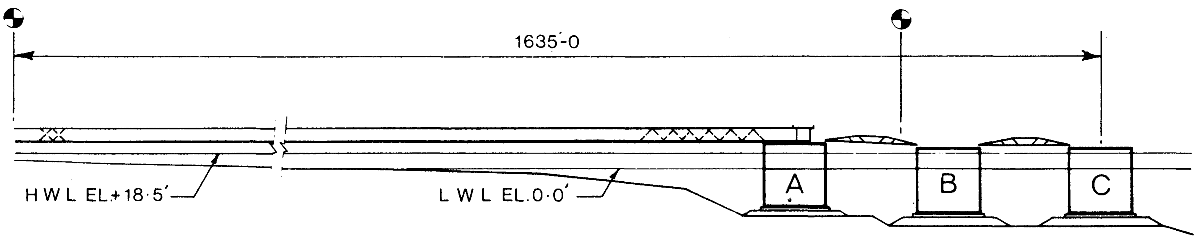


deep water oil terminal wharf
Hadlow Cove Quebec

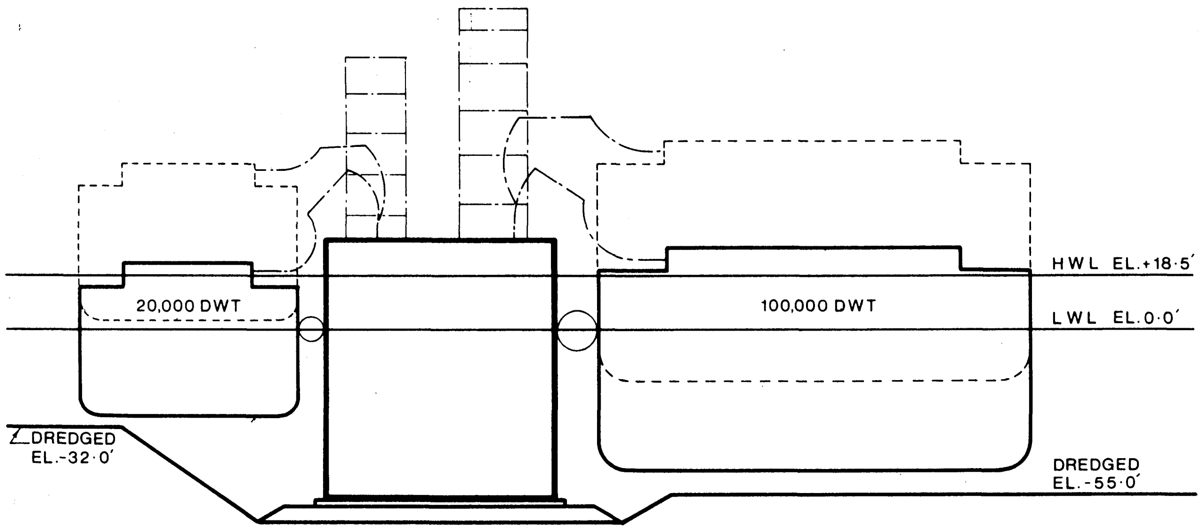
fig.1



east west elevation



north south elevation



cross section at cell 3

fig. 2

WHARF AT HIGH TIDE IN HEAVY WINTER ICE
General view of the wharf on 4 February 1971

FIG 3

CLEARING OF BERTHS BY ICEBREAKER
View of wharf at falling tide on 11 March 1971

FIG 4