The St Petersburg Flood Protection Barrier: design and construction

Peter Hunter

HR Wallingford, Wallingford, UK (p.hunter@hrwallingford.co.uk)

Presented at CETMEF PIANC Paris 2012

Abstract

Since the founding of the city of St. Petersburg in 1703, the low-lying areas of the city have suffered from flooding caused by storm surges travelling up the Baltic Sea. These occur about once each year, due to high winds and low barometric pressure causing surges in sea level.

To protect the city, a barrier over 25km long across the estuary of the Neva River has recently been completed. It was opened by the Prime Minister of the Russian Federation in August 2011. This paper describes the planning, design, construction and operation of the project, which has cost about $3 billion.

The barrier includes the following main components:

- embankment dams
- 6 sluice complexes to accommodate river flow
- a 200m wide main navigation channel, closed with two very large sector gates
- a secondary navigation channel 110m wide, closed with a vertical gate
- navigation channels for shipping to approach the two navigation openings
- a highway forming the western section of the outer ring road around the city
- a road tunnel under the main navigation channel
- a viaduct with a lift bridge above the secondary navigation channel.

1. Introduction

The primary function of the barrier is to reduce the risk of flooding to the City of St Petersburg and its surrounding area. Subsidiary functions are:

- allow normal river flows
- maintain a year round navigation channel for ocean-going vessels
- maintain a separate navigation channel for river vessels during ice free months
- provide a six lane highway as part of the St Petersburg ring road.

Figure 1: Location of the Barrier

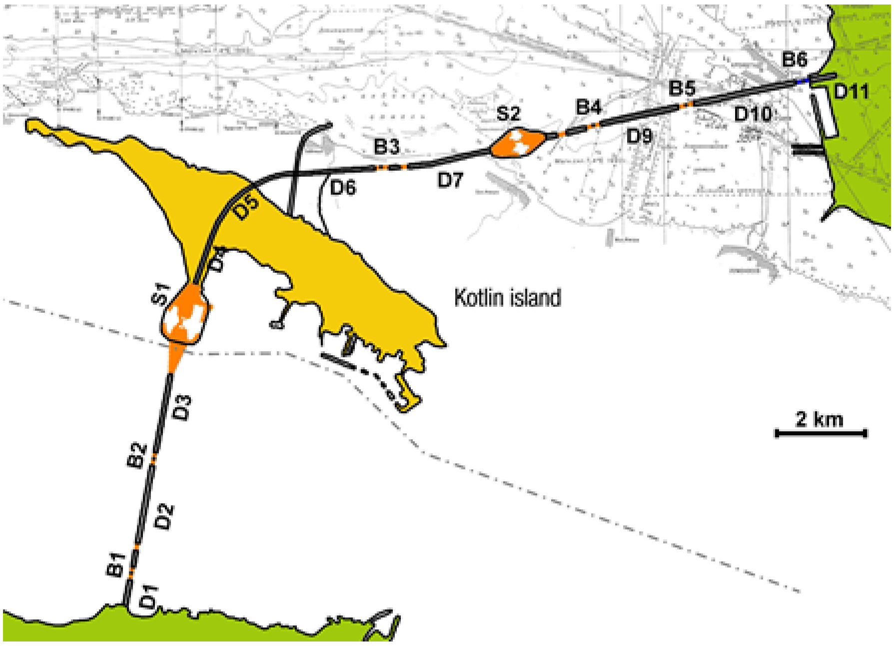

Figure 2: Layout of Dams (D1-D11), Sluices (B1-B6) and Navigation Openings (S1 & S2)

2. Flooding

The city of St. Petersburg has a population of about five million, and is the second city of Russia. It was founded by Peter the Great in 1703 in a low-lying area where the delta of the river Neva meets the waters of the Gulf of Finland at the eastern end of the Baltic Sea. High water in the Gulf causes flooding of the low areas of the city, and flooding has been a concern since the city's foundation.

There are no measurable tides at St Petersburg. High sea levels are caused by the interaction of wind and low atmospheric pressure causing surges to move eastwards up the Gulf of Finland. Flooding occurs when water level reaches +1.60m BS (Baltic System Datum, approximately mean sea level). Between 1703 and 2002, a total of 295 floods with peaks higher than +1.60m BS were recorded, that is about 1 per year. There are indications that flood frequency is increasing: in the 22 years between 1980 and 2002, 46 floods occurred, which is about 2 per year. The City's worst flood was in 1824, reaching +4.21m BS, when 300 people died. This can be compared with the surge in the southern North Sea in 1953 of 3.36m above predicted tide levels, that led to catastrophic flooding in the Netherlands and the UK.

Analysis of annual peak levels since 1703 has led to selection for design purposes of an estimated peak level of +4.55m BS with a return period of 1000 years. The Barrier will give protection against floods with a return period of 10,000 year.

Storm surges typically cause water levels to be above flood level (+1.60 m BS) for about a day, although occasionally for up to three days. The River Neva rises in Lake Ladoga, 70 km east of St Petersburg. It has a mean discharge of 2500 m^3/s, and flows do not vary greatly during the year. When the barrier gates are closed the water level upstream will rise at about 0.5 m/day, which can be tolerated. Had the barrier been located much nearer to the city, the rise of water level due to the river flow during barrier closures would have been unacceptable.

With the present population, a flood to +3.0m BS, which has a return period of 50 years, would be catastrophic. It would lead to damage to public infrastructure such as roads, bridges, flooding of the metro system, overflow of sewerage systems and serious flooding of buildings.

The benefits of the barrier were assessed in the pre-feasibility study and again in an economic assessment study. Benefits were measured as expected avoided costs of flood damage to buildings and city infrastructure (including roads, water, electricity) and loss of economic activity. Assessments were based on the statistical forecast of flood frequency and flood levels. The total average annual direct damage was estimated at USD 94 million at 2002 prices, and would now be substantially higher. This excluded any estimate of the cost of damage to the contents of buildings of cultural value, largely located in the low lying city centre, including the Hermitage and many other museums.

3. Project history

Construction of the Barrier started in 1980 and by 1984 Kotlin Island was connected to the northern coast via the Barrier. In 1987 construction was temporarily halted because of concerns about the possible environmental impact of the Barrier on pollution levels in Neva Bay. In 1990, an International Commission of experts confirmed that the impact of the completed Barrier on the environmental would be minimal. Although these results were generally accepted, work continued at only a minimal pace. Work between 1987 and 2002 was largely limited to maintenance of works already completed.

In 1995 the European Bank for Reconstruction and Development (EBRD), working with the City of St Petersburg, commissioned a Pre-Feasibility Study to evaluate the technical, economic and environmental feasibility of completing the Barrier (ref. GIBB 1995). This demonstrated that the Barrier should be completed.

In 2001 the Russian Government agreed with the EBRD that detailed feasibility studies should be completed, including a technical feasibility study (NEDECO, 2002a), and an environmental impact assessment (NEDECO 2002b). Following successful completion of these studies, in December 2002 the Russian Government and the EBRD signed a loan agreement to allow completion of the Barrier to commence. Two other banks, the European Investment Bank and the Nordic Investment Bank, also took part.

In 2004 a team of Russian and European Consultants led by Halcrow was appointed to review and complete the barrier design. The EBRD appointed Jacobs as Lender's Supervisor, and they are supported by HR

Wallingford. In 2005 a team of consultants was appointed to act as Project Manager/Engineer to work with Gosstroy of Russia, the Government Department responsible for construction and operation of the Barrier, during the procurement of the contracts identified as necessary for completion of the Barrier. These are listed in section 7 below.

Figure 3: S1 Navigation Opening

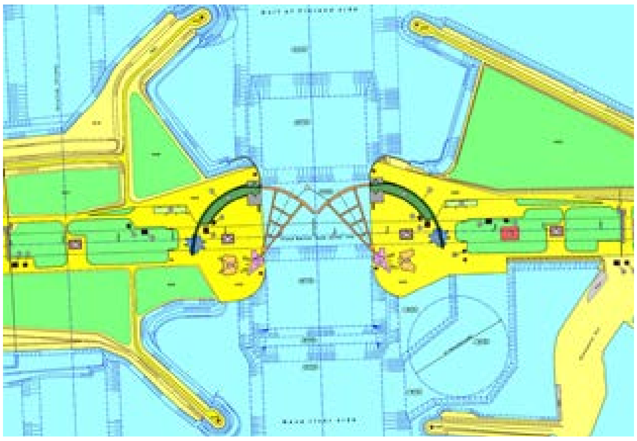

Figure 4: S1 Navigation Opening :plan

4. Environmental assessment

The Environmental Assessment Study reached the following overall conclusions:

- The completion and the operation of the Barrier are designed to meet relevant Russian and EU environmental and health and safety standards.
- The completion of the Barrier has no significant negative impacts on the environment of Neva Bay and the Gulf of Finland compared to the existing situation.
- There will be a partial return to Pre-Barrier conditions in water flows north and south of Kotlin and in the general circulation pattern.
- Safety of navigation to and from the ports will be increased because the navigation channel will be wider and smaller vessels will be separated from the main channel.
- The existing environmental problems in Neva Bay and the Gulf of Finland (e.g. water and sediment quality) were primarily associated with other activities in and around St. Petersburg. The completion of the Barrier will have no direct effect on these.

The overall benefits of the completion of the Barrier for the city of St. Petersburg in a general sense can be summarised as:

- No further risk of human and economic losses incurring from flooding.
- Full protection of the extensive cultural heritage of the city against floods and damage.
- Creation of a more beneficial situation for making investments in the city territory.
- Possibilities of creating recreational areas along the reclaimed territories.
- Improved navigational safety.
- Increased employment in St. Petersburg and especially in Kotlin during the construction period.

Figure 5: Tunnel construction beneath S1 navigation opening

5. Project components

The barrier, which is 25.4 km long, is located across the estuary of the Neva River. It includes the following main components:

- 11 rock and earth embankment dams, separated by sluices or channel openings
- 6 sluice complexes each with 10 or 12 gates to accommodate flow between the Neva bay and the Gulf of Finland
- a 200m wide main navigation channel to allow for ships of 100,000 DWT capacity , which can be closed with two sector gates
- a secondary navigation channel 110m wide to allow for smaller ships, which can be closed with a vertical gate
- navigation channels for shipping to approach the two navigation openings
- a road constructed on the embankment dams, forming the western section of the outer ring road around St Petersburg
- a road tunnel under the main (S1) navigation channel
- a viaduct with a lift bridge above the secondary (S2) navigation channel

Figure 6: S2 Navigation Opening: plan

Figure 7: Gate at S2 Navigation Opening (in maintenance position)

6. Design

In a project of this magnitude and in this location, as expected there have been many challenging design issues. The details of some of these continue to be developed as construction proceeds. The most notable design features and issues have included the following:

- Design of sector gates for S1 navigation opening (200m wide and 16 m deep)
- Hinge design for S1 gates
- Design of S1 gates in order to avoid hydraulic instability during closing.
- Design of vertical lifting gate for S2 navigation opening (100 m wide, 7 m deep)
- Confirmation of the design parameters including wind, wave and ice loading
- Design of foundations for all structures on subsoils comprising a wide variety of clays, loams and sands, including glacial deposits containing pebbles and boulders as well as lacustrine glacial clayey deposits varying between hard and very soft.
- Design for operations in temperatures down to - 39.0 ºC
- Gate design for operations in sea ice up to 60 cm thick
- Design of road bridge with lifting section at S2 navigation opening
- Design of highway tunnel beneath main shipping channel at S2 navigation opening
- Interface with the Flood Warning and Forecast System
- Interfaces between barrier operating system and barrier decision support system

The sector gates closing the S1 navigation opening are floating gates normally housed in dry docking chambers. They are closed by flooding the docking chambers and floating the gates into their closure positions. The gates are each 110 m wide, 22m high, 132 m radius, and each weighs 2650 t. The hinge for each gate is a steel sphere in a bronze socket, 1500 mm diameter with a maximum load of 11 000 tonnes. The S2 gate is 110 m long, 11.8 m deep, and weighs 2600 t.

Following experience gained during the design of the Rotterdam flood defence barrier during the 1990s, (after the design of the St Petersburg Barrier), particular attention was given to the need to avoid oscillations of the S1 gates during opening and closing, and alternative designs were model tested to determine the optimum solution. The original gate design was modified as a result of this testing, with a ‘hydrofoil’ installed along the lower edge of each gate. In addition a ‘soft landing system’ of dampers was installed to allow the gates to settle on the concrete sill without excessive impact forces. The hydrofoil and the soft landing system had be fit within the dimensions of the already completed docking chambers.

Figure 8: Sluice B1 (one of six sluice gate complexes along the barrier)

There are six sets of sluice gates along the barrier, with a total of 64 gates each 24 m wide, with a combined total weight of over 10 000 tonnes.

Designs have been in accordance with Russian standards, taking into consideration other international standards where appropriate. Approvals are required by various government departments and ministries, with a final coordinated approval issued by the state body Glavgosexpertise.

7. Construction

Construction in a marine environment is never simple, and construction in the Russian winter presents its own unique challenges. Sea ice can be more than 50 cm thick, and on average temperatures fall below zero on 175 days per year. Concreting is normally continued in temperatures down to -20.0 ºC, at which point providing an environment for high-quality concreting is no longer practicable. Dredging and reclamation using floating plant is not feasible during winter months, which can extend from November to April.

Figure 9: Foundation construction - Dam D3

As well dealing with the climate, the other major constraint is ensuring that channels remain open at all times for shipping and for river flows. This means that new navigation openings must be complete before the existing navigation channel can be closed. Near the planned S1 navigation opening, a large part of dam section D3 was left open to maintain the original navigation channel until ships could use the S1 navigation opening and new channel.

Significant attention was paid to maintaining safe standards of construction operations throughout the project, and there were few incidents during the course of construction.

The partly completed Barrier already reduces storm surges that threaten to flood the city, so that flood levels in the city are lower than before. However it would not prevent catastrophic flooding in the event of an extreme surge. Furthermore, serious floods could damage incomplete sections of the Barrier, and therefore high priority is being given to completing the flood protection works. The highway along the barrier (including the tunnel beneath the main navigation opening) is due to be completed in 2011, two years after the flood protection works.

For any project of this size finding adequate sources of construction materials is a critical factor, and designs of the dams took into account the availability of suitable armour stone and other construction materials.

The embankment dams and sluice structures were partly built before 1987, and current construction is packaged into the following contracts:

Contract A1: Sluice B1

Contract A2: Dam D3 and southern tunnel sections and ramp

Contract A3a: Navigation Structure C1 – Civil Works

Contract A3b: Gates for Navigation Opening S1 & Sluices B1-B6

Contract A4: Navigation Structure C2

Contract A5: Power, Control and Communications

Contract A6: Dam D2 and Sluice B2

Contract A7: Dredging under S1 Cofferdam

Contract A8: Northern Dams and Buildings

Contract A9: Sluices B3 to B6

In addition there is the new St Petersburg Navigation Channel, which is not a formal part of the flood protection project. Most contractors are from the Russian Federation, although there are also contractors from the Netherlands and Germany.

8. Costs

The cost of completing the barrier was about $3 billion. More than 50% of this total can be attributed to the provision of the six-lane highway, including the tunnel under the main navigation channel and the bridge across the S2 Navigation Opening.

9. Conclusion

Construction of the 25 km barrier to protect St Petersburg commenced in 1980, although the present phase of construction started only in 2004. Substantial flood protection was provided by 2010, when the gates could be closed. The project was substantially complete by 2011 and is now protecting St Petersburg from the risk of serious flooding. On 26-28 December 2011 all the gates were closed for two periods, each of over 12 hours, when flood warnings were issued. The city was protected against a forecast flood level of

281 cm above normal, which was the most severe event for over 50 years. This is the first major flood to have been averted by the barrier, and would otherwise have caused substantial flooding.

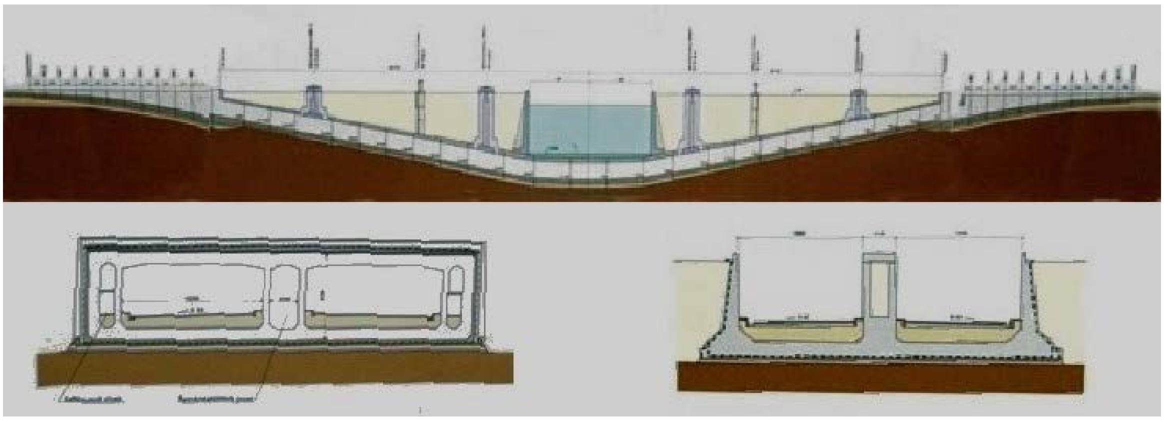

Figure 10: S1 Navigation Opening - tunnel sections

Acknowledgements

This paper has drawn on information from various sources, particularly the references listed below. Opinions in this paper are the sole responsibility of the author, who represents the Lender's Supervisor on behalf of the EBRD.

References

GIBB 1995: St Petersburg Flood Protection Barrier - Pre-Feasibility Study, Sir Alexander Gibb & Partners (1995)

Nedeco 2002a: St Petersburg Flood Protection Barrier Environmental Impact Assessment. Nedeco consortium with WL | Delft Hydraulics et al, 2002

Nedeco 2002b: St Petersburg Flood Protection Barrier Technical Feasibility Study.

Nedeco consortium led by Royal Haskoning with Lenhydroproject, Lenmorniiproject et al 2002

Jacobs 2012: Flood Forecasting and Decision Support Systems Phase 2 Review,

Jacobs UK Ltd with HR Wallingford & Deltares, October 2012