STRENGTHENING OF THE OLD QUAY WALL AT SUOMENLINNA DRY DOCK


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Abstract. Suomenlinna (Sveaborg) is an inhabited sea fortress built on six islands which now forms part of the city of Helsinki, the capital of Finland. The dry dock is located at the heart of the fortress.

The height of the dry dock basin walls varies depending on the elevation of the base rock. The wall face is composed mostly of concrete and partly of ashlar masonry.

The basin has been systematically modified and renovated over the time and contains structures from many periods. It has also been enlarged and deepened by blasting. A section of approximately 9 m (width) by 11 m (height) of the northern corner of the concrete basin wall supporting the floating door had deteriorated from exposure to seawater and frost damage. The structure suffered from water leakage into the basin at increasing rate despite of an earlier attempt to repair it in 2009.

The process of restoration in 2012 was commenced by stabilizing of the damaged gravity wall using two grouting pipes (114.3 x 5 mm) with 120 of 10 mm holes per meter, driven 2.0 m deep into bedrock. Having had the gravity wall stabilized, the structure could be tieback anchored by Titan 40/16 anchors, followed by installing a new concrete wall. The anchors were drilled through the existing structure to the depth of 3 m into the bedrock. A drainage system was installed and steel reinforcing bars were attached to the anchors before a new concrete wall was placed using least-invasive formwork. The drainage system was also fitted with heating cables to ensure its operation during prolonged sub-zero conditions.

The instability of the damaged structure made work challenging, especially from the work safety point of view which required implementing extremely careful safety precautions and diligent approach with precisely planned stages of workflow. This approach, together with close monitoring of progress and ability to resolve challenges effectively as they had arisen was the only way how to carry on work and achieve successful completion of the project.
1 INTRODUCTION

Suomenlinna (Sveaborg) is a sea fortress which was built on a group of islands at the entrance to Helsinki harbor in 1748. Its architecture and landscape have been shaped by several historical events, and the fortress has served to defend three different sovereign states over the years: the Kingdom of Sweden, the Russian Empire and, most recently, the Republic of Finland.

The fortification became a strategic military shipyard with one of the biggest dry docks in the world, comparable to the fortress at Gibraltar. In 1991, the fortress was added to the UNESCO World Heritage List as a unique monument of military architecture.

Suomenlinna is the property of the Finnish government and it is managed by the Governing Body of Suomenlinna. It is an agency subordinate to the Ministry of Education and Culture.

Today, Suomenlinna is one of Finland’s most popular tourist attractions. It is also a district of the city of Helsinki, with a permanent population of more than 800 (Table 1).

Table 1: Suomenlinna at a Glance – Fact sheet.

<table>
<thead>
<tr>
<th>Suomenlinna</th>
<th>Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>80.0 ha</td>
</tr>
<tr>
<td>Surrounding sea</td>
<td>80.0 ha</td>
</tr>
<tr>
<td>Number of islands</td>
<td>6</td>
</tr>
<tr>
<td>Length of walls</td>
<td>about 6 km</td>
</tr>
<tr>
<td>Number of buildings</td>
<td>200 [160,000 m²]</td>
</tr>
<tr>
<td>Number of inhabitants</td>
<td>about 850</td>
</tr>
</tbody>
</table>

2 SUOMENLINNA AS A WORLD HERITAGE SITE

One of the most successful projects ever undertaken by the United Nations Education, Scientific and Cultural Organization (UNESCO) is the international cooperation launched under the World Heritage Convention adopted in 1972. The convention aims to promote international cooperation to identify and protect cultural and natural heritage of outstanding universal value.

Suomenlinna was added to the UNESCO World Heritage List in 1991 on the grounds of I meeting criterion (iv), which classified the fortress as an outstanding example of a type of building or architectural ensemble that illustrates a significant state in human history.

According to an evaluation by ICOMOS, Suomenlinna stands as an outstanding example of the principles of fortification typical for its time and the history of military architecture and also features special characteristics.

When Suomenlinna was added to the World Heritage List, a buffer zone was defined around it, terminating at the city centre of Helsinki in the north and the military district in the east and south. Located on islands, the fortress is not threatened by city planning or traffic. A building plan of minimal construction has been designated. No changes to the surrounding area that could threaten the values of the site are planned for the near future (Figure 1).
2.1 Intactness and authenticity

Suomenlinna consists of a series of defensive and utility buildings in a way that the architecture and functionality of the fortress blends with the surrounding landscape. Most of the fortifications and utility buildings from both the Swedish and Russian eras have been well preserved. The fortress has only a few buildings from the Finnish era, and they all retain their own distinctive identity.

The fortifications from different periods, the surrounding environment and the various buildings from different eras make Suomenlinna an ensemble with its own characteristics preserved with respect to the architecture, building materials, and building methods. Traditional construction methods are favoured to ensure the preservation of the area, and the open spaces and areas of the site are utilized in a manner that respects the cultural and historical values of Suomenlinna.

2.2 Environmental changes, effects and challenges

The possibility of a sharp rise in sea levels owing to climate change constitutes a threat to the site, as it would accelerate the erosion of coastal structures. Similarly, increased rainfall causes damage to wooden and stone structures. The increase in visitors has also caused sand-banks to erode during the summer.

Although the affected zone constitutes a relatively small part of the site’s total area, the erosion is managed with reports and by restricting visitors’ access to the vulnerable area.

3 PRESERVATION, MAINTENANCE AND ADMINISTRATION

The actual preservation, restoring and maintaining of the fortress is the responsibility of the Governing body of Suomenlinna that has been undertaking repairs on the fortress for three decades.

The Governing Body’s activities are guided by a maintenance and development plan. The agency also cooperates closely with the National Board of Antiquities and the City of Helsinki.
3.1 Management plan for Suomenlinna

The Management Plan of the Suomenlinna World Heritage Site guides the preservation and development of the site. It consists of several levels of priority for putting the long-term goals into practice.

The basic principle of the plan for the use of Suomenlinna is that restoration and reconstruction are to be carried out taking both antiquarian and architectural considerations into account.

The top priority embraces the idea crystallizing the conservation of the World Heritage Site. It is a clear vision of the Suomenlinna of the future which is shared by all.

4 AREA DESCRIPTION

Built on a cluster of rocky skerries, the fortress consists of an irregular network of bastions. The majority of its buildings date from the late 18th century. The original fortress, completed with a dry dock, was built from local rock and was fortified using a system of bastions over varied terrain.

The fortress was later augmented with sandbanks, barracks and other various buildings in the 19th century. There are also dozens of historical underwater sites around the fortress.

4.1 Dry dock description and background

The dry dock is located at the heart of the fortress, on the north side of Susisaari island. The construction of the dry dock began in 1750. With galley basin, lock gates and paternoster device, it was the state of the art in the 18th century technology.

Since Finland’s independence (1917), the dock has had several occupants. The State Aircraft Factory used the repairs workshop for assembling airplanes in the 1920s. Later, the dock was taken over by the State Shipyard and was converted into a submarine base. After the Second World War, the ships required for Finland’s war reparations were built there.

Today, the dock area and its buildings are leased to a commercial repair dock and a private association that uses the large dry dock as winter storage and repair facility for old wooden sailboats (Figure 2).
5  MANDATE AND SCOPE OF WORK

Restoration of fortifications and old buildings of Suomenlinna requires considerable expertise.

The leading authorities for the project, The Governing Body of Suomenlinna and the City of Helsinki, were represented at the site by Architect Tuija Lind.

The mandate of KAREG Consulting Engineers was for the design-build, project management and construction management of strengthening of the old quay wall of Suomenlinna. As the construction progressed, the first author deemed necessary to take additional measures in regards to structural planning, work execution by adopting pro-active and hands-on approach. Because of complex and challenging conditions, the mandate of KAREG Consulting Engineers was extended to providing alternative solutions such as modifying concrete and grout composition, steel structure, and also drainage system design and installation, thus some design work had to be done in-situ.

The phases of the old quay wall strengthening, in particular drilling, injection, anchoring and drainage system installation was undertaken by contractors, sub-contractors and sub-trades under the supervision of the author. The author firmly believed that along with maintaining design integrity and thoughtfully balancing architectural design recognition with feasible structural planning it was important to assure the project was being carefully and precisely executed with minimal disruptions and that diligent safety precautions were enforced.

The project of strengthening of the old quay wall was undertaken during summer months. First phase started in the summer of 2011 and was ceased just before winter of 2011. In the spring of 2012 the construction work resumed and the project was finalized in September 2012.

6  STRENGTHENING OF OLD QUAY WALL AT SUOMELINNA DRY DOCK

The dry dock has been systematically modified and refurbished over the time, and consists of structures from many periods. It has also been enlarged and deepened by blasting.

The wall face is composed mostly of concrete and partly of ashlar masonry. Behind the wall face there is a gravity wall made of masonry debris from the building site containing mostly hard rocks, bricks, and lime mortar. The height of the dry dock basin walls varies depending on the elevation of the base rock. The bottom level is about – 8.0 (Figure 3).

Figure 3: Supporting corner of the floating door. Section. Construction phases and periods.
One of the main causes of deterioration is through ageing and degradation of the mortar which is invariably lime based in this old structure. It was obvious that the quay wall has suffered the abuse of constant exposure to fluctuating elements, in particular of sea water and frost damage.

The process of restoration and strengthening of the quay wall at Suomenlinna was a complex and comprehensive project which required throughout planning, designing and attentive approach during all stages of the workflow. It entailed, but was not limited to supporting corner of the floating door stabilization, drainage system design & installation, formwork and a new concrete wall installation.

6.1 Options for strengthening – concepts and methods

Old walls are failing strength assessments and it is necessary to undertake remedial measures by a suitable method. In addition, many old walls are prone to inadequate stability. That being said, any strengthening proposal must satisfy the requirements of both strength and stability as necessary. Since the quay wall merits heritage status, it follows that methods of refurbishment and strengthening should be acceptable in an aesthetic as well as structural sense.

Initially, there were two premeditated concepts for strengthening of the wall. First was based on the fact that the basin is filled with water which would mean that the project would be executed underwater by divers. The other approach presumed that the basin was emptied and the work was carried out in the dry dock. Both concepts have significant advantages, but also drawbacks.

An important advantage of the underwater approach is that there is no risk of water pressure from behind the wall. The disadvantage is that the quality of work, in particular exactness and correctness could be significantly compromised under such conditions and circumstances. Another issue would arise from the fact that there was continuous vessel traffic and ships were coming in and out of the dock. It would be impossible, or extremely expensive, to stop the traffic as the shipyard operates as a private company.

The dry dock concept had major advantages in terms of cost-effectiveness and time-management. It also offered essential flexibility as the dock could be filled with water in 8 - 12 hours for incoming vessels and emptied between 8 – 16 hours in order to resume construction work. The shortcoming was to accommodate incoming traffic of vessels which required a great deal of flexibility, scheduling and coordination of construction work with the vessel transit which was at times unforeseen. Decidedly, the benefits and advantages of the dry dock prevailed.

7 SUPPORTING CORNER OF THE FLOATING DOOR STABILIZATION

7.1 Temporary basin wall stabilization

The supporting corner of the floating door at the dry dock was made in 1932. Over the years, a section of approximately 4 m (width) by 11 m (height) of the corner of the concrete basin wall supporting the floating door had deteriorated from exposure to seawater and frost damage and was in a poor state of repair.

Further damage and disintegration of the structure was caused by water leakage through the wall at an increasing rate despite an attempt to recondition it in 2009.

The wall of the supporting corner was vulnerable with a high rate of dimensional instability. As the test in-situ confirmed, the concrete wall was in an excessive and unacceptable level
of permeability which greatly impacted overall strength and stiffness of the structure (Figure 4).

![Figure 4: Dimensions of the supporting structure (wall) of the floating door.](image)

### 7.2 Pre-strengthening tests and parameters

No specific standards are available for assessment or refurbishment of existing old structures thus accurate values for material properties are not always necessary. This is fortunate since little or no data appear to be available for typical durability and stiffness of old structures.

#### 7.2.1 Wall injection test

The objective of the test was to find out whether it is possible to reduce permeability of the structure by 30 – 40% by filling in the existing cracks with mortar. The second goal was to ascertain whether the structure is strong and stiff enough for the selected strengthening scheme which involved drilling and anchor installation.

The test was enacted in the summer 2011 on the site. It initiated by drilling a vertical hole, $\phi = 90$ on the level +2.05 m to the depth of 1.5 m on the bedrock. The hole was then grouted using Finnish made grout Fescon 600/3, max coarse particle: $\phi = 3$ mm. The quantity of grout used was around 100 l and the theoretical amount was 76 l. It means that about 24 l of grout was dissolved in water, or distributed into pockets. The duration of grouting was $2 \frac{1}{4}$ hours. Taking into account the fragility of the wall, the test was made without using injection pressure, and only gravity pressure of a 1 meter height was applied.

As it later showed, the injected grout increased durability and permeability of the wall only for short time and in about two months the condition of the wall was back to its original state of fragility. It was presumed that the wall is excessively porous and permeable and that the injected material was broken down and flushed out of the structure. Another finding was that the composition might not have had the required rate of viscosity and water/binder ratio.

Based on the outcome of the in-situ test, it was determined that before the actual strengthening could take place, a temporary stabilization of the wall had to be done. After careful consideration of all possibilities, the first author concluded it was most favorable to perform temporary basin wall stabilization by installing grouting steel pipes.
7.2.2 Material properties tests

A series of experimental tests was performed in the end of 2011 and beginning of 2012 by the first author.

The purpose of the tests was to determine the structure and composition of the used grouting material for temporary stabilization of the wall. It was important to find a reasonable choice of water/binder ratio to guarantee desired sorptivity, permeability and overall strength of the grout.

The composites used were ready mixed bags Pagel V1/1, max coarse particle: $\phi = 1$ mm, and Masterflow 928, max coarse particle: $\phi = 1.8$ mm, both with admixture RheoMATRIX 100.

For testing, the author of the paper used coarse gravel 0….16# presuming that it would best imitate the condition and composition of the old structure. The gravel was put in the water where the grout mixture was then injected. The material was tested for viscosity, hardening time and distribution adhesiveness.

The test proved that Masterflow 928 was more suitable as it had the needed properties. The test also showed that the holes in the steel pipes must be $\phi = 10$ mm instead of $\phi = 5$ mm to guarantee better distribution and diffusion of the grout in the existing structure.

7.3 Steel pipes installation

The process of restoration of temporary stabilization of the damaged gravity wall was initiated using two vertical grouting steel pipes (114.3 x 5 mm) with 120 holes per meter, $\phi = 10$ mm, driven 2.0 m deep into bedrock, drilled and installed on the level +2.05 m. The penetration into the bedrock was essential for the structural stability of the wall.

7.4 Grout injection

Cementitious grout was used in preference to an epoxy based material as it was considered important to have materials that are compatible with the wall.

In order to lessen the water pressure on the structure, the pipes were injected while the basin was filled up with water that was used for counter-pressure. The grout, Masterflow 928 with admixture for achieving a higher degree of viscosity, was poured applying only gravity pressure, using so-called “contractor’s method”. The sock was designed to contain the grout and prevent unsightly leakage through cracks that may have been present. It also permitted controlled leakage of grout to enable a structural connection to be formed with the surroundings.

The predicted response of the wall calculated beforehand and based on assumed values for the material properties was within the measured values, bearing in mind the wide range of uncertainties in relations to the wall stiffness and strength.

8 WALL STRENGTHENING USING TITAN ANCHORS

Having had the old corner stabilized, and water from the basin pumped out, the structure could be then tieback anchored.

8.1 Preparatory work – timber wedges installation

In order to cease and prevent supplementary water leakage from the structure, the old, traditional method of timber wedges was employed (Figure 5).
8.2 Titan injection anchors 40/16 installation

The anchors design installation was based on the hydraulic pressure of $+2.0$ m, water level: $\text{max} = +1.85$ which is equal with the level of the supporting corner.

The Titan anchors 40/16 Combi-coat were drilled through the existing structure to the depth of 3 m into the bedrock using rock crown drill bit of $\phi = 90$ mm with centralizing spaces 88 mm. The reason for the large crown drill bit was that the denoted location of the bedrock was based on expert assessment using available data, therefore there was a slight, but potential probability that the anchors could have been as well bonded in the old, underwater structure (Figure 6).

Figure 6: Design drawing. Vertical injection pipes. Titan anchors. Stainless steel pipes for drainage. Detail of the washer plate and spiral stirrup of anchor. Scale 1:50.
There were twelve (12) Titan anchors installed with spacing of 1.35 m (horizontally) and 2.0 m (vertically) to secure optimal anchor performance. The anchor inclination angle was between $10^\circ$ – $20^\circ$. Because of the continuous water leakage, the two upmost holes had to be Purgel-injected in order to break off the water flow. The corresponding anchors were injected in a higher inclination angle using Masterflow 928 as a grouting aggregate. All other anchors were injected using standard Portland cement-based grout. In this project, the anchors also have a function as tension bars and they were not post-tensioned.

The behavior of the wall and anchors was closely monitored for safety reasons.

The ultimate load based on constant elongation of 0.2 % is 660 kN and the yield load is 525 kN. According to long time tests in aggressive environmental conditions, the sacrificial loss of the Titan anchors is 30% after 120 years. The maximum used anchor load was 251.3 kN thus safety factor was 1.46 ($525\text{kN}/251.3\text{kN} \times 0.7$). As Figure 7 demonstrates, anchor load of #10 anchor was 132.7 kN. The allowable working load by using total safety factor 2 and shaft friction value (bond value) 250 kN/m$^2$ equals 141.4 kN, which is greater than 132.7 kN ($0.5 \times 0.09 \text{ m} \times 3.14 \times 4.0 \text{ m} \times 250 \text{kN/m}^2$).

9 DRAINAGE SYSTEM INSTALLATION

The original design of drainage system needed to be altered and re-designed in-situ since for its proper functionality it was essential to take into account the actual “routes” of water leaks in the structure.

The system consisted of two one-pipe routes and one two-pipe route (total 4), of the length between 7 – 8 m. They were installed vertically on the structure using plastic tubes DN 50, applying the conventional “drainage in shotcrete” method, and partially insulated. The vertical tubes were then attached at the bottom to the horizontal stainless steel pipes (total of 4, $\phi = 60$) that conveyed water to the basin.
The upper end of each plastic tube was secured with an attachment for maintenance purpose. The drainage system was fitted with heating cables to ensure its operation during winter as frozen water would expand its volume and cause damage.

9.1 Restoration & Preservation vs Renovation

The process of drainage installation, and in particular, heating cables placement and their positioning elicited a discussion over a fine line between restoration and preservation on one end, and renovation and proper functionality of the drainage system on the other end. The opponents of the idea argued that such addition is a major interference of the established restoration procedures for structures with heritage value. The proponents, on the other hand, defended the idea emphasizing that the benefits of heated drainage system prevail over the authenticity since they would undoubtedly extend lifetime of the structure.

10 REINFORCING BARS INSTALLATION

The length and quantity of concrete reinforcing bars was determined in-situ (Figure 8).

Placing of the vertical, high-bond bars, $\phi = 20\,\text{mm}$ was with spacing $160\,\text{mm}$. For the horizontal, high-bond bars, $\phi = 16\,\text{mm}$, installation was performed with spacing $100\,\text{mm}$.

The used steel stress in SLS for the max bar size $20\,\text{mm}$ was $210\,\text{MPa}$ and then less than $240\,\text{MPa}$ and the max bar spacing was $160\,\text{mm}$ and then less than $200\,\text{mm}$. It means no special crack prediction is needed (EUROCODE 2).

After proper positioning and securing the concrete reinforcing bars, they were then later cut and bend to desired length and shape.

One important reason for placing the reinforcing steel properly is to achieve the right amount of concrete between the reinforcing steel and the surface of the concrete member. Cover is the single most important factor in protecting reinforcing steel from corrosion. It is also necessary to assure that the steel bonds to the concrete well enough to develop its strength. The requirements for minimum cover are usually listed in the project specifications or shown on the drawings. In this case, the thickness of concrete cover was $50\,\text{mm}$.
11 FORMWORK

Because of lack of continuity and so-called “togetherness” of the wall, and also due to its heritage value, it was not suitable to use standard, double-sided formwork. The only alternative was to apply ready-made single-sided type of formwork. It was furnished with Trio and SB2, manufactured by the company Peri Ltd. This system enabled to have the wall face leaning inwards at the angle of the original structure (between 3° – 4°).

The panels of the formwork were anchored against sliding and tension by Dywidag bars of ϕ = 20 mm into the bedrock up to 3 m deep, as opposed to the conventional horizontal anchor system. This method was chosen to guarantee the least-invasive work approach to preserve the structure to the greatest extent possible (Figure 9).

In addition, the selected formwork lining imitated the pattern of the original concrete structure so that the process of restoration would fully comply with the preservation principles also from the aesthetic point of view.

12 NEW CONCRETE WALL INSTALLATION

The concrete strength was C 40/50. In addition, it had to meet the following exposure requirements: XC4 (wet and dry changes), XS3 (seawater environment with frost).

Transportation and delivery of concrete mass to the side was arranged by a local ferry carrier. Specific admixtures for water reducing and for retarding concrete set were added during transportation to the site.

The theoretical rate of climb was between 0.5 m/h – 1.0 m/h, and the concrete pressure was between 31 - 40 kN/m². The height of concrete in formwork was 5.5 m. Total pouring time was 10 hours. The approximate quantity of concrete used to build a new wall was around 19.0 m³. The thickness of the new wall was uneven (average 0.90 m, measured from the old masonry stone mix).

13 CONCLUSIONS

- The strengthening scheme presented is an economic and aesthetic solution to the refurbishment, restoration and preservation of understrength and unstable wall of the dry dock of Suomenlinna.
- The use of the selected strengthening option and technique for structural intervention of the wall of the dry dock was found to be an appropriate technique to achieve the desired objective and at the same time being minimal invasive, quick and discreet when compared to conventional strengthening techniques. In addition, the selected method has proven effective in keeping the wall in as close to its original condition as possible for many years to come.
- Our work is a reflection of the respect we have for heritage structures and the magnificent work of the architects, masons and craftsmen who have gone before. We preserve their legacy by following the established restoration procedures and lending our experience to the collaborative process that is critical to heritage conservation.

14 REFERENCES