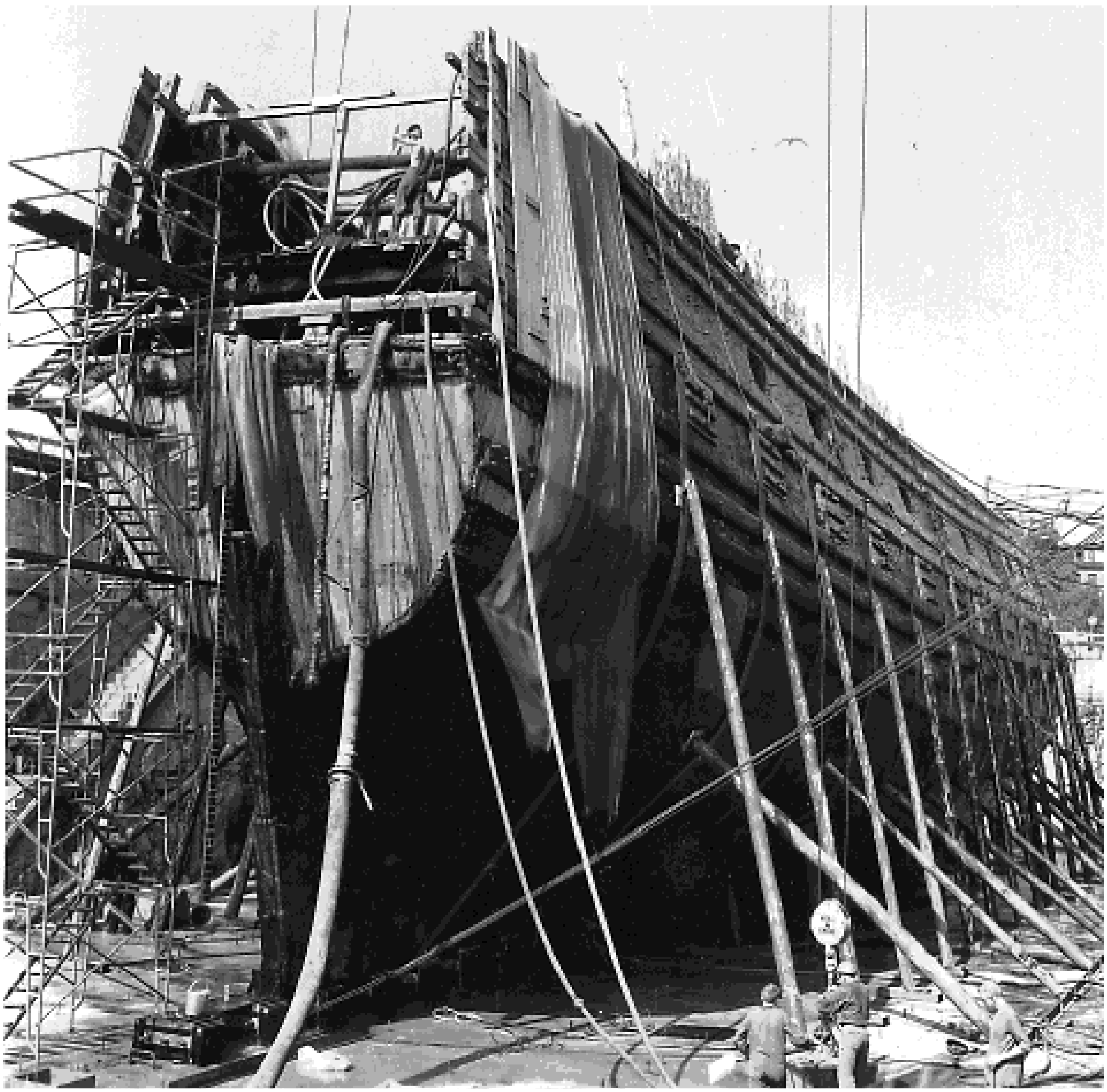
CONSERVATION OF THE SWEDISH WARSHIP
VASA
FROM 1628

Birgitta Håfors



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Preface to the 2nd Edition

In the beginning of the sixties, conservation of waterlogged archaeological wood became an important topic in the museum world. The Swedish warship Vasa was salvaged in 1961 and a few years later, two other archaeological large-scale wet site projects were started, namely the excavation of the Danish Viking ships at Skuldelev and the the medeival cog in Bremen. The testing and development of conservation strategies and practical procedures was a largely unexplored field at the time, and the intense work in the sixties, seventies and eighties by the conservators at the Vasa museum became of seminal importance for the preservation of Vasa, as well as other water-logged artefacts. Birgitta Håfors has been a key person in this work since 1961, and she summarized the work in the comprehensive report from 2001 on the conservation of the Vasa hull and the several thousands of loose objects. Since then, she has continued work with this material, in particular the role of the conservation agent, polyethylene glycol (PEG), in the preservation process.

Since the publication of the first edition in 2001, continued preservation work and front-line international research on the chemical and mechanical changes occurring in the wood of Vasa has been pursued by the Museum in co-operation with national and international institutions and laboratories. A prerequisite for a successful work in this field is detailed documentation on all actions taken during the earlier stages of the preservation.

It is therefore a great pleasure for SMM to publish the present updated second edition of Håfors' report, which will be of great use for the continued efforts to preserve the Vasa and other large water-logged artefacts. The Museum is very grateful for her enthusiastic and dedicated work to complete this documentation.

Stockholm, August 2010

Marika Hedin	Lars Ivar Elding
Director¸ Vasa museum	Scientific co-ordinator

Preface

The preservation of the Swedish warship Vasa from 1628 is the largest undertaking of its kind in history. A large, black, waterlogged wreck has been transformed into a preserved museum piece of world renown, the centrepiece of the most visited museum in Scandinavia.

The road covered in the process has been difficult and at times bumpy. In 1960, no museum had ever preserved a waterlogged wooden object of anything near the size of the Vasa. New methods had to be drawn up, tested and applied, while experts put forward their opinions, which were not infrequently diverging. As was often the case during the Vasa adventure, problems were solved by a combination of professional knowledge, commonsense and daring feats of imaginative thought.

At no time was the going rougher than during the prolonged discussions in the 1970's about when to stop spraying the hull with polyethylene glycol (PEG). The decision to discontinue the treatment was appealed against to the Government and eventually led to the resignation of the then head of conservation.

The Vasa Museum is now pleased to present this documentation of the preservation of the Vasa. This book focuses on the preservation of the hull and covers the period from the raising in 1961, via the PEG treatment in the temporary Wasavarvet Museum from 1962 to 1979, the subsequent slow drying period, and the transport to the permanent museum in 1988, to the accommodation of the vessel in the new premises in the early 1990's.

We believe that this documentation will be useful for museum colleagues working with large waterlogged wooden objects, and we also hope that it will be an interesting case for science or museum studies.

For its achievement in preserving the Vasa, the Museum is profoundly grateful to the conservation staff, a small but dedicated group of professionals, working in sometimes very difficult circumstances. In particular I should like to mention the late Mr Lars Barkman, M.Sc., head of conservation in the pioneering years from 1961 to 1978. The contribution of the Board of Conservation Specialists (Konserveringsrådet) with the voluntary participation of the foremost experts in fields such as wood chemistry and technology, polymer technology, ventilation and naval architecture has been (and continues to be) crucial for a successful preservation project. This is also shown by the many references to the activities and opinions of the Board in the present work.

Finally, I should like to thank the author of this documentation, Mrs Birgitta Håfors, M.Sc.. She has participated in the preservation of the Vasa since the early days of the project, first as a chemist, and from 1978 to 1995 as head of conservation. During this long period, she has acquired an immense knowledge about the preservation of the Vasa material and of the history of the preservation project. No person could be more suited than she to pass on that experience to future generations.

Stockholm, January 2001

Klas Helmerson
Director, Vasa Museum

INTRODUCTION

The Commission

At the meeting of the specialist board for the conservation of the Vasa on 6 February 1976, the member Ernst Abramson drew attention to the large number of documents that was accumulating during the work with the conservation of the Vasa. He pointed out the desirability of arranging and working on those documents so that they could be of use to other institutions in the same field. The same issue was again raised on 5 August 1977. This time the meeting recommended that the museum director as soon as possible should see that the documentation of what had up till then been done regarding conservation measures was started. The next time the question of the documentation of the conservation work was raised was on 16 October 1978 when the museum director informed the meeting of specialists that Lars Barkman, after seventeen years as head of conservation of the Vasa project, had resigned from his position. The meeting expressed great concern regarding the danger of delay in the documentation work that this might lead to.

The specialists, did not however, give up the subject. At the meeting on 21 March 1979, a memorandum by Abramson was discussed. This described how the documentation should be carried out, and the meeting also recommended that a suitable member of the conservation staff should be charged with the task of executing the commission.

This time, the museum director presented the matter to the board of the museum. On 15 May 1979, the Board of the National Maritime Museum decided that three aspects of the Vasa project were to be documented. The first was the history of the Vasa project from 1956 to 1964. The second was the conservation of the Vasa and the third was the restoration of the ship. The three commissions, in the order mentioned, were entrusted to Gillis Claus, myself and Lars-Åke Kvarning. At that time I had been working with the Vasa project for nearly eighteen years.

The Planning

The conservation project, however, needed much attention at that time, and this affected the documentation project. The work was started on a small scale and it remained on the agenda at the specialist meetings. First a schedule of reports on the conservation treatments of all categories of material that were represented in the Vasa project was prepared.

The main subject was however the treatment of the Vasa hull and the large disconnected wooden finds. Because a chronological report was suggested in the discussions of the meetings of the specialists, I made out a plan with the Vasa hull as central object. The chronology of measures taken to carry through the process of preserving and drying the hull and the monitoring work involved was chosen as the backbone of the report. The disconnected constructional timbers and sculptural adornments that were treated in tanks would get their own chapters. The research work that had been my original task on the Vasa project would be the subject of a separate report.

The Documentation Work

In 1985, the conservation project had reached a stage that would allow some time to be devoted to the documentation report. To obtain some idea of what working method would be adequate, I was asked first to write a report on the work of developing the method of treating and mounting the Vasa sails as a smaller assignment. That report was finished in March 1985. I then started work on the main documentation report. To help exclusively with this, I was given one assistant for the registration of the archive material and one assistant to systematize the large amounts of measurement data from the monitoring activities. The work continued until the task of managing the actual conservation situation for the Vasa in the permanent Vasa museum demanded our full attention.

The Report

In 1995, it was decided that the documentation report would be put into focus again as my main task for a period of three years. The matter was brought to the attention of the group of specialists who, with old and new members, still remained at the disposal of the Vasa museum. The specialists have all shown great interest in the documentation work and have provided many useful suggestions. However, the report unfortunately had to be reduced to the backbone of measures regarding the hull, as being the most spectacular and demanding task of the Vasa conservation project. This means that there will be other reports concerning other aspects of this project.

Acknowledgements

The documentation work has been a long and time-consuming project and many assistants and colleagues have been of great help. I hereby wish to express my gratitude to them and especially to the specialists who, as the body called the Conservation Council, have given generously of their knowledge and competence both to the conservation and to the documentation project.

Täby, December 2000

Birgitta Håfors

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Chapter 1

THE FIND

The Vasa

During the early 1620´s, Sweden was at war defending and trying to expand her territory to the south of the Baltic Sea. For this task, the naval fleet was of the utmost importance. Therefore, the King of Sweden, Gustav II Adolf, planned to enlarge his fleet and in January 1625 a contract of lease for the Stockholm Naval Shipyard was signed with two brothers, Henrik Hybertson who was a naval architect and former shipbuilder at the Stockholm Naval Shipyard and Arendt Hybertson de Groot who was a businessman with good contacts with suppliers both in Sweden and in Holland (3, p 19). The contract included the construction of four new ships, two larger and two smaller ones. The keel lengths of the larger ones were ordered by the King to be 135 feet, which is about 45 metres. The two smaller ones were to be built to the same size as a named older vessel which had a keel length of 108 feet, which is about 36 metres. There has been some confusion as to the identity of the ships built in accordance with this contract, but investigations made by Curt Borgenstam and Anders Sandström into the shipyard archives have led them to suggest that the Vasa was the first of the ships mentioned (3, pp 63-71).

Although the shipyard had other contracts to fulfil, preparations were made for building one of the smaller ships in 1625. In the fall of 1625, however, the naval fleet lost ten ships in a storm on their voyage home from battles in the south of the Baltic. Among them were several large ships, and the King decided to make up for the loss as fast as possible. Consequently he wrote home from the battlefield and gave orders that the next ship to be constructed should have a keel length of 120 feet. This caused a great deal of trouble to the shipbuilder who had collected timber and already laid the keel for one of the smaller ships of the contract, but he obviously changed his original plans and started to build the Vasa. The keel of the Vasa is 135 feet long and is constructed from four pieces joined together. The many pieces could be the result of the shipbuilder changing the 108 feet keel of a smaller ship into the 135 feet keel for the Vasa (3, p 20)

The warships at that time were built mostly of oak. In Sweden, the oak forests grew only in the southern parts and they belonged to the Crown and to the nobility. The accounts of the Naval Shipyard (4) show that oak was delivered from those forests and was also bought from Poland, northern Germany and Holland.

The keel of the Vasa was laid late in the year 1625 and she was probably launched in the summer of 1626, which means a very short building period for the hull. She was then completed and set sail on her maiden voyage on 10 August 1628. This voyage lasted for two hours. Most of that time the ship was kedged in the shelter of the cliffs of the harbour to a situation where she would be able to start sailing. There, as a breeze caught her canvas, she heeled over and the water gushing in through the open gunports caused her to sink right in the harbour entrance.

Attempts to recover the Vasa were immediately started by Ian Bulmer, a British engineer who received a writ of privilege to salvage the Vasa dated 13 August 1628. He managed to bring the hull to an upright position standing on her keel as early as 21 August that year, but attempts to raise her to the surface failed (10, p 772). Several experts, one after the other, received contracts for salvage of the wreck but the attempts proved fruitless and they were eventually abandoned.

Most of the cannons were however salvaged in the 1660´s by Albrecht von Treileben. According to an undated list specifying thirtynine cannons, twenty-six of a total of forty-eight 24 pound cannons were salvaged. They were marked G.A.R.S and 1627 as year of casting (10, p 814).

The cannon that was salvaged in 1958 from the Vasa wreck was marked with the same letters, but with 1626 as year of casting. This strengthened the understanding that the wreck found in 1956 was in fact the Vasa that capsized in 1628 (11).

Relocating the Vasa

The Vasa was relocated in 1956 by the Swedish engineer Anders Franzén. He had after many years of archive studies in a private capacity gained knowledge about what was the most likely area in the Stockholm harbour in which to find the place where the Vasa foundered. The position was not exactly pinpointed and the search was performed from a small motorboat with a grappling iron and a core sampler of Franzéns own design (8, p 31).

Even after travelling 30 - 40 metres down through water the core sampler could cut a sample from a wooden object, and this was what happened on 25 August 1956. When it was recovered from the bottom of the Stockholm harbour after having been put to work on an indication from the grappling iron, the core sampler contained a piece of black oak. This showed that there was some sunken oak material at that spot on the bottom of the harbour.

Franzén persuaded the Swedish Navy to let their divers make an investigation on the site, and this was carried out from 4 to 9 September 1956. On that occasion, despite poor visibility, chief diver Per Edvin Fälting found gunports in a wooden construction on the bottom and realized that it must be a huge man-of-war. The divers went down on a couple more occasions in the autumn of 1956 to take some measurements, and in November of that year a large mast was salvaged which, even though it was broken, measured 19 metres. This mast turned out to be the foremast.

On the basis of the measurements taken and the dimensions of the mast, although he mistook it for the main mast, sea captain Sam Svensson who was restorer at the Swedish National Maritime Museum made a suggestion about the dimensions of the wreck. He also produced a sketchy drawing dated January 1957, depicting the wreck with three gundecks. He estimated the length of the keel to be 122 feet, that is about 40 metres, and the width to be 35 feet, that is about 11 metres.

The Salvage Decision

The wreck that had been found off the island of Beckholmen in the Stockholm harbour area was declared under protection as a historic monument on the initiative of the Swedish National Maritime Museum. As it was identified as a man-of-war, it belonged to the Swedish Naval Forces. At a meeting of the Navy´s museum committee, held on 25 September 1956 to which the Head of the Swedish National Maritime Museum, Gerard Albe, was invited, the possibility of salvage was discussed.

In December 1956, the Navy´s museum committee suggested to the Naval Administration that a committee for the salvage and preservation of the ship should be formed. This was also suggested by Franzén in a memorandum dated January 1957. The committee was formed in the spring of 1957. It was called "Vasa-kommittén" and its instruction was to investigate the possibilities of a salvage operation.

On 21 February 1958, the committee´s report was finished. It was structured into five parts dealing with a) the technical possibility of salvage b) an estimation of the costs c) a time schedule d) the organization of the project and e) a proposal for a museum location and building (7).

The Organization of the Salvage Project

At the beginning, Edward Clason who was Commodore of the Swedish Naval Forces was the leader of the salvage project, first in his capacity as head of the Naval dockyard and, after he had retired from that position, as appointed leader of the project. As the project gradually grew, a special organization, "Wasanämnden" was created by the Government on 30 September 1959, based on a proposition from the National Maritime Museum and the Naval Administration. The charge given to this organization was to manage the salvage of the Vasa and related tasks.

"Wasanämnden" functioned until l July 1964, on which date the responsibility for the Vasa was transferred to the National Maritime Museum.

The Salvage of the Hull

The diving operations were recommenced on 29 April 1957. The object was to obtain enough information to be able to decide about the possibilities of salvage. The work performed during that diving season was devoted mostly to tagging and measuring the wreck carefully in order to get a more accurate idea of its shape and dimensions. This work resulted in a plan showing the deckbeam compartments of the hull and gave a figure of 45 metres for the length of the keel, as a correction of the earlier figure estimated by Svensson.

In Clason´s final report for the year 1957, a figure of 50 metres or maybe a little less was given for the length of the hull and 12.2 metres for its width. The height was more difficult to measure, but by comparing measurements made on the wreck with figures from the literature about the ship "Vasa" that foundered in 1628, the height from the keel to the aftcastle was estimated to be about 14 metres.

Clason also added a note that the hull was almost completely built of oak.

In the following year, 1958, the diving operation started on 15 April. This year´s work consisted mainly of digging tunnels under the hull for the lifting wires. During the previous season, the decision was taken that no loose objects should be brought to the surface unless they were a hindrance or endangered the divers´ safety during the measuring work. When the tunneling work began, the loose finds that were in the way had to be salvaged and the objects that were pumped up together with the dredging material had to be taken care of.

On 5 September, the first cannon was taken from its original situation on the lower gundeck and brought to the surface. This provided the final proof that the wreck in fact was the "Vasa". The nine metre tall rudder was taken ashore towards the end of the diving season. The total number of salvaged objects in December 1958 was 404 pieces of different sizes.

A new drawing of the hull was added to Clason´s report for the year 1958.

During 1959, the tunneling work was completed. Cradled by steel cables, the hull was lifted with two pontoons and moved in stages to shallower water where more accurate measurements could be made. These confirmed the earlier measurements.

Among the objects salvaged that year were the figurehead lion and a 15 metre tall piece of the central part of the main mast. The 1959 diving operation brought the total of objects to 930 pieces.

During the following year, 1960, diving was carried out with the hull at its new location. The upper gundeck was dredged and about 140 cubic metres of mud were removed. The dredging operation left a layer of mud that was supposed to be of a suitable thickness to keep the finds in their positions on the deck. The pumped-up sludge was sifted, so that small objects would be recovered. Some large objects that constituted a hindrance to the work were also brought to the surface.

At the place where the ship foundered, the three metre thick layer of mud that covers the mineral clay layer of the sea bottom was excavated, an operation which gave about 500 objects belonging to the Vasa.

The Excavation of the Hull

On 24 April 1961, the hull was finally lifted, and on 4 May, the Vasa was towed on her own keel into the Naval dockyard´s largest dry dock, the Gustav V (GV) dock. There, a specially constructed pontoon was waiting to receive the hull. At that time, the excavation had already started because it was important to rid the hull of clay and mud as soon as possible in order to ease the internal pressure.

During the summer of 1961, the whole interior was excavated and the finds taken ashore. Wooden objects constituted the greater part of the material. In addition to some constructional parts, this material consisted mostly of objects belonging to the crew and the ship´s equipment as well as inner decorations like panelling and sculptured objects. Among these was an orchestra consisting of seven wooden sculptures each about 90 centimetres in height that were found on the upper gundeck. Chests for personal belongings and the ship´s stores, barrels for food and warfare material such as lead bullets and gunpowder, gun carriages and a large number of blocks belonging to the rigging were among the objects, the total of which amounted to 16 000 registered finds when the excavation was finished on 29 September 1961.

The Diving Operations, 1964 - 1967

After the hull had been salvaged, a plan for a systematic search of the foundering site was made. In order to carry it out, divers were working at the site through every summer season during the years 1964 - 1967.

During the first year, only 89 objects or pieces of objects were recovered. In 1965, the number went up to 430 including such spectacular finds as the large carved starboard beakhead railing and one of the big Vasa anchors. In the 1966 diving operation, the coat of arms of the Vasa family held by the figurehead lion was recovered among a total of 254 finds.

It was decided that 1967 would be the last year during which diving operations were to take place. It yielded 1073 finds, including the right hindleg of the figurehead lion. As a last effort, the longboat and two of the total of four large Vasa anchors were salvaged with the assistance of "Lodbrok", the big floating crane in the Stockholm harbour. After that, the place where the Vasa foundered was empty as far as could be established by the divers, who dug test trenches in different directions from the depression made by the ship in the bottom clay.

The diving operations during 1964 - 1967 thus gave a total of 1946 finds.

Chapter 2

THE ORGANIZATION FOR THE PRESERVATION OF THE VASA

Responsibility for the Preservation

The head of the technical department of the Swedish National Antiquity Board and National Historical Museum, Arne Strömberg, was a member of the Vasa Committee, and the National Antiquity Board continued to take responsibility for the preservation of the Vasa objects that were salvaged, first through Strömberg and then, during his leave of absence, through his deputy, engineer Tore Boström, even after the committee´s work had been finished. Some of the preservation work was also performed by the conservation department of the National Antiquity Board.

When the Board of the Vasa (Wasanämnden) was established in 1959, it took over all responsibility for the Vasa project, including the preservation.

This involved:

deciding upon the proper handling of the material

seeing that proper storage facilities were available for the huge amounts of different materials salvaged from the sea, including the Vasa hull

ensuring that the most suitable preservation methods were employed for the various materials

seeing that the necessary equipment and staff were made available to carry out the treatments

making sure that proper storage and exhibition spaces were available for the preserved material

Throughout the salvage period, the handling and storage of the objects were the responsibility of the leader of the salvage operation, i.e. Clason. As no knowledge was available within the Naval Administration concerning how to take care of waterlogged material, Clason had instructions that advice should be sought from the National Antiquity Board (28, p 3, Fynd §1). On the basis of advice given by the Board´s conservation department, instructions were given to the staff handling and storing the objects.

The problem of taking care of the objects grew, however, with the growing amount of salvaged material. This made the Board of the Vasa decide that their technical department would be expanded with a conservation authority whose responsibility it would be to take decisions on questions concerning the handling and treatment of the objects. In July 1960, the Board of the Vasa appointed Boström, who was at that time deputy head of the technical department of the Swedish National Antiquity Board and National Historical Museum, to take on this responsibility.

The first four aspects of the preservation responsibility mentioned above were fulfilled by the Board of the Vasa, while the fifth, i.e. the work leading to the construction of a permanent Vasa museum that would guarantee long-term conservation of the object, became the duty of the Swedish National Maritime Museum, which took over the responsibility for the Vasa project on 1 July 1964.

The Conservation Council

The increasingly more complicated preservation decisions were taken by a group of specialists established in September 1960 under the chairmanship of Boström. The members were the wood specialist, Bertil Thunell, and the impregnation specialists, Lars Birkner and Rolf Morén. Birkner, who was employed by the Boliden Mining Company, concentrated on the fungicidal aspect, while Morén's particular area of competence was the dimensional stabilization treatment of wood.

It was expected that the Vasa hull would contain objects made of various materials and maybe some remnants from food stores. To make sure that every kind of material that was found would be taken care of in a proper way, it was necessary to seek advice from several specialist fields. To meet these new demands, the Board of the Vasa created a permanent board of scientific and engineering specialists at a meeting on 18 August 1961, in accordance with a proposal put forward by Hans Hansson, who was head of the museum department of the Board of the Vasa. At the same meeting, Hansson was also appointed chairman of the board of specialists, which was called the Conservation Council of the Board of the Vasa.

This Conservation Council covered the field of wood material through Erik Björkman, who was a specialist in the degradation of wood by microorganisms and fungi at the Royal College of Forestry, Hans Holmgren, who was a specialist in the protection of wood against decay, and Bertil Thunell, who was a specialist in the material properties of wood at the Swedish Forest Products Research Laboratory and later Professor at the Royal Institute of Technology. The areas of glass, ceramics and bone were covered by Tore Boström and Arne Strömberg, textiles and leather through Hans Axelsson from the National Swedish Institute for Materials Testing, and food through Ernst Abramson from the National Swedish Institute of Public Health. These specialists were placed at the disposal of the Board of the Vasa by their respective institutions, with no cost to the Vasa project.

Because of their connection with industry and various university institutions, the specialist board members were able to arrange contacts between other specialists and the conservation department. Specific conservation problems could be solved by defining applicable parts of them as thesis topics for university examinations at one of the board member's own institution or could be introduced by a board member specialist to another appropriate university institution. In July 1963, the conservation of the Vasa sails brought the polymer specialist, Bengt Rånby, into the group and two of his students wrote their M.Sc. theses on the conservation of the Vasa sails.

The Conservation Council held its first meeting on 5 May 1961, the day after the Vasa had made the journey into the dry dock floating on her own keel. At the meeting, the specialists decided that they would consider that they had the authority to make management decisions in conservation matters. The head of the conservation department would, however, be allowed to make management decisions by himself in urgent matters after consulting the appropriate member of the Conservation Council. This interpretation of the authority of the Conservation Council was however disputed because the council had no official appointment and could not thus take upon itself the responsibility of management (151).

On 1 July 1964, when the responsibility for the Vasa was transferred to the Swedish National Maritime Museum, the Conservation Council that had been established by the Board of the Vasa ceased to exist.

The conservation of the vast amounts of waterlogged materials called, however, for continued specialist assistance. Hence the board of the Swedish National Maritime Museum decided on 16 June 1964 to establish a new Conservation Council for the conservation of the Vasa. The museum's board turned to the members of the former Conservation Council of the Board of the Vasa and appointed Thunell chairman of the new Conservation Council. Museum director Per Lundström was appointed vice-chairman. Besides specialist competence in the field of wood material, the board of the museum appointed the specialist on metals, Olle Arrhenius, and the food specialist, Ernst Abramson, to be permanent members of the new Conservation Council. To cope with upcoming problems relating to other materials categories, the museum director was authorized to appoint one more permanent member to the Conservation Council. The head of the newly formed Vasa department at the National Maritime Museum, Lars-Åke Kvarning, was appointed secretary and the head of the conservation department, Lars Barkman, was to be rapporteur regarding the status of the conservation proceedings. The new Conservation Council was only meant to have an advisory status and not to have the authority to make management decisions in conservation matters.

The new Conservation Council took the decision at its first meeting to call in Erik Björkman, Bengt Rånby and senior naval architect Gunnar Schoerner as additional members (figure 2-1).

Figure 2-1 The members of the Conservation Council 1964 - 1972. Standing from left to right: Bengt Rånby, Olle Arrhenius, Lars-Åke Kvarning and Ernst Abramson. Sitting from left to right: Erik Björkman, Per Lundström, Bertil Thunell and Lars Barkman (photo: Göran Sallstedt)

The Conservation Council appointed by the Swedish National Maritime Museum performed its work in the same manner as the one formerly appointed by the Board of the Vasa. The specialists suggested methods and continuously followed the preservation procedures through reports given by the conservation department.

At the beginning of 1972, permanent member Arrhenius asked to be dismissed. On his recommendation, Åke Bresle was appointed to the Conservation Council as a replacement. Bresle took part in the meetings from October 1972 until January 1974. At the end of 1973, co-opted board member Björkman died, and no replacement was appointed. Permanent member Abramson asked to be dismissed in February 1976, but agreed to remain as consultant. The board of the Maritime Museum appointed Rånby as a permanent member of the Conservation Council instead of Abramson. From September 1975 to February 1988, Gillis Claus represented the board of the Swedish National Maritime Museum at the meetings of the Conservation Council.

The pontoon superstructure had only been a temporary housing for the Vasa hull, and when more settled plans for a permanent Vasa museum came into existence in 1979, technical competence in addition to that already represented by the Conservation Council was needed. Thunell, as chairman of the council, suggested to the board of the Maritime Museum that the Conservation Council should be reconstructed. The board of the Maritime Museum agreed to the suggestion and the Conservation Council for the conservation of the Vasa was reconstructed on 1 July 1980 to become a council for technical questions with a widened field of responsibility. Its competence should cover the whole of the collection of the Swedish National Maritime Museum.

Thunell was appointed chairman of the Technical Specialist Council. The vice chairman and secretary were, as before, Lundström and Kvarning. This situation remained until 1 October 1987 when Kvarning succeeded Lundström. Klas Helmerson, who had twenty years of experience of the Vasa project became Kvarning´s successor in the museum organization and also secretary of the Technical Specialist Council (139). The former specialist council members Rånby and Schoerner also became members of the Technical Specialist Council. Claes Allander from the Royal Institute of Technology, who had been advising on the amelioration of the ventilation and climatizing of the pontoon superstructure after the automatic spraying had been shut off, became a member of the Technical Specialist Council when a ventilation specialist was needed to represent the council at the meetings concerning the planning of the permanent Vasa museum.

The Technical Specialist Council has remained as a permanent advisory group for the conservation of the Vasa ship and the various preserved materials in the permanent Vasa museum, and its members still function as contacts with industry and institutions. Allander succeeded Thunell as chairman from the fall of 1989 when the latter was taken ill. Ingvar Johansson from the Swedish Institute for Wood Technology Research came in as a wood specialist at the same time. In December 1995, Johansson was appointed chairman of the council after Allander had tendered his resignation. As ventilation and climatizing specialist, Allander was succeeded by Bengt Ljungquist from the Royal Institute of Technology.

From 1997, the Technical Specialist Council was again given the name and function of Conservation Council for the long-term conservation of the Vasa. In the summer of 1997, chief inspector John Sjögren joined the Conservation Council as an expert on ship construction. Apart from these changes, the members of the Conservation Council have remained the same.

The Conservation Department

As the volume of the preservation work grew, special staff had to be employed to carry it out and a conservation department was formed by the Board of the Vasa. The duty of this department was the management and execution of the conservation work. The execution of it came to fall into two main areas of activity, the hull and the loose objects made of different materials. The disconnected wooden parts of the hull were included in the latter category.

The treatment of the hull took place in the pontoon superstructure that was at the same time the temporary Vasa museum with full access for visitors throughout the day for more than 360 days per year.

The disconnected structural parts were stored in watertanks at the Swedish Naval Dockyard premises. In May 1961, the preservation activities temporarily acquired a three-room apartment in an old house situated near the National Maritime Museum building. This was used for the storage of small objects and as an office. Even the chemistry work of developing the conservation solution was started in that apartment.

New premises adapted to these purposes were however under construction on the precincts of Beckholmen belonging to the Swedish Naval Dockyard. These were ready for use early in 1962, at the same time as the pontoon superstructure for the hull of the Vasa was completed.

The new conservation building was equipped with two large tanks, one measuring 20 x 2 x 1.15 m and the other 20 x 1.65 x 1.15 m for treating the loose wooden objects. It also contained a chemical laboratory.

Conservation Management

In May 1961, Lars Barkman, who was a chemical engineering graduate was employed as a full-time conservation manager and head of the conservation department. He had been preceded by Boström who had held this post since late in 1960 on a part-time basis of one working day per week.

Barkman held the post of head of the conservation department until October 1978 when he moved to the corresponding post at the Swedish National Board of Antiquities and National Historical Museums. Birgitta Håfors, who was then head of the research and analysis laboratory, succeeded him as conservation manager and head of the conservation department.

Conservation Work

In November 1960, Torsten Cronvall was hired full-time as foreman for the preservation work. In January 1961, added competence was brought to the conservation department when Bo Lundvall, who had been an assistant conservator at the technical department of the National Antiquity Board and National Historical Museum was given full-time employment at the department as conservator.

The manual work connected with putting material into water storage and performing preservation activities had been the responsibility of the technical staff under the salvage management´s command. When Barkman became full-time head of the conservation department, a number of untrained labourers were acquired under his command to take over those duties.

The different kinds of materials called for different skills in conservation and, in the autumn of 1961, Sven Bengtsson was employed at the conservation department as conservator. In 1963, an assistant conservator, Britta Risfors, who was a chemical engineer, was employed as a full-time member of the staff. During 1965, Risfors quit her employment and Birgitta Johansson, also a chemical engineer, became assistant conservator.

In December 1971, Johansson asked to be relieved of her post as assistant conservator. The special conservation work that had been the responsibility of the assistant conservator had progressed to such an extent at that point in time that it was decided that it was not necessary to replace her.

Besides the permanent staff, specialists were working as consultants on some preservation jobs.

Spray Treatment of the Hull

At the same time as Barkman became head of conservation, the full-time foreman was replaced by a half-time works manager. The post was filled by appointing Knut Svensson, who was near retirement and was a mechanical engineer of vast industrial experience. This post was mainly created for the technically complicated task of treating the hull of the Vasa. After having successfully put the first spray system for the hull into operation, Svensson retired. The works manager's post was then made full-time and Arne Stolth succeeded Svensson in the spring of 1962.

Apart from those among the conservation staff who had special areas of competence, a number of untrained labourers were employed for among other things the spraying of the Vasa hull.

To begin with, the Vasa was sprayed by hand, but in March 1965 an automatic spray system was installed that made it possible to reduce the staff for the spraying task from seven to two full-time employees. The automatic spray system, however, called for added competence and continual maintenance. An electrical engineer, Sture Bruse, who could also take full responsibility for the management of the spray system was therefore added to the staff.

When the frequency of sprayings was reduced during 1975, one of the two untrained labourers who had been working with cleaning out the sprays during the spraying activity was assigned to other tasks.

In July 1979, the two engineers who had been managing the spraying of the hull were given employment in managing the museum buildings. The staff employed on the conservation of the Vasa was thus cut down by half, i.e. five people since 1969.

Research and Monitoring Work

People with special competences were also needed and, in the autumn of 1961, Birgitta Håfors was hired in her capacity as a chemist. In October 1962, an untrained assistant for chemical laboratory work was employed as a full-time member of the research and analysis laboratory staff. The work load at the research and analysis laboratory was growing and, in October 1966, a post as laboratory engineer was created. This was filled by Gunilla Lögdström who was a chemical engineer. On 1 July 1968, engineer Lögdström quit her employment and Maija-Liisa Antonen, who was a part-time student of chemical engineering, was hired as laboratory assistent. When she in turn asked to leave in August 1969, the post was filled by Ulla Ekholm, who was an experienced chemical engineer, but only for 50% of the full working hours.

At the end of 1973, the permanent post of an untrained laboratory worker, which was created on 15 October 1962, was abolished and one year later, when the then holder of the laboratory assistant position, Lena Svensson, a chemical engineering graduate, resigned her position, that post was also abolished.

In October 1978, Barkman resigned the position as head of the conservation department and was succeeded by Håfors. The post of research and analysis chemist was not refilled, but the position of laboratory engineer was re-established and that post was filled by chemist Marija Nilsson

Establishing the Permanent Vasa Conservation Department

In 1965, the staff of the Vasa conservation project had reached its largest number of eight trained persons and five or six untrained labourers on a regular basis. At times with great workloads, extra labourers and laboratory assistants were hired. In 1979, when the tank treatment of the loose wooden finds was finished and the spraying of the hull had been stopped, the project organization could be trimmed to suit the permanent needs for the maintenance of the Vasa.

The staff with special competence remaining on the project had then been reduced to three persons.

On 1 July 1984, a change in the organization of the Swedish National Maritime Museum took place. As a consequence, the field of responsibility of the conservation laboratory was expanded to cover the whole of the collection of the museum, as was the case with the Technical Specialist Council. This meant that the staff of the conservation laboratory had to split their working hours between the Vasa project and other conservation projects, so that less time was devoted to the Vasa project. This was foreseen as a means to preserve the diversified competence necessary to maintain the Vasa as a museum piece when the need for working hours on the project had diminished.

Chapter 3

MEASURES PRIOR TO AND SUPPORTING THE CONSERVATION

The Vasa Underwater Site

The bottom of the sea at the place where the Vasa was found was described by Anders Franzén in the following way "the uppermost layer down to a depth of about two metres consists of a black, semi-organic silt of very low density that has beneath it a relatively rigid post-glacial clay deposit with a thickness of about five to ten metres that in its turn rests on solid rock" (22).

Vasa was standing upright on her keel when she was found. The keel stood about 2.5 metres down in the geological clay. The clay layer that had some sand mixed into it reached up to the third plank below the lowest wale. On top of the clay, there was a layer of mud and silt that was between two and three metres thick on the hull´s port side nearest to the land and thinner on the starboard side of the hull. The Vasa hull had obviously created a barrier for silt and brick and other debris coming from activities on land. The silt layer that reached almost to the lower gunports on the port side created a protection for the wood. The interior of the hull was also filled with silt.

The starboard side of the hull was more exposed to the sea water than the port side (23). The part of the Stockholm harbour where the Vasa sank had been subjected to harbour activities for a long time, and the nearby island of Beckholmen had been used for tar production since the 1630's. Measurements made in 1943 revealed a concentration of 7.0 mg of hydrogen sulfide per litre seawater in the neighbourhood of the Vasa underwater site (figure 3-1) (12).

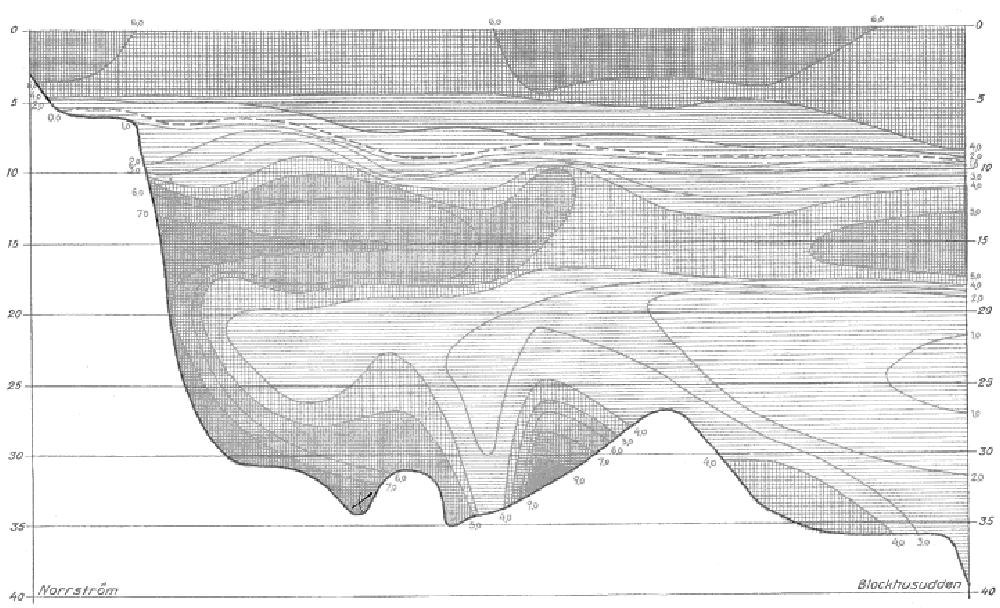

Figure 3-1 Diagram of the conditions of the water of the Stockholm harbour 22 September 1943, "X" denotes the situation of the Vasa wreck (from "Vattenhygien Nr 2 och 3, årg 1, 1945", p 45). The scale denotes the depth in metres. The figures at the bottom contour denote the hydrogen sulfide content in mg per litre.

Because of the archipelago protecting the Stockholm harbour and the measures already taken in the 16th century to block entrances to the harbour by putting stone constructions into them, it seems likely that a situation with a very low oxidizing capacity prevailed even in 1628 when the Vasa sank (1). This means that there was only a limited degree of biological and chemical degradation of the wood constituents.

As for the iron in the hull construction and onboard the Vasa, there has been enough dissolved oxygen to cause corrosion to the ferrous state. Some of the corrosion products have precipitated on the surface of the hull where they have formed a large number of iron- containing stalactite- and stalagmite-shaped structures. This has been interpreted as confirmation of low water movement round the Vasa hull on the bottom of the sea (1). The dissolved iron has also penetrated the oakwood and formed a chemical complex with tannins in the wood. Thus a large part of the oakwood of the Vasa has a blackish colour.

The Raising of the Hull

Supports and Reinforcement of the Hull before the Final Lifting

In its final report, the Vasa committee expressed some apprehension that tension created during the drying process might cause deformation of the timbers of the Vasa hull. This would make it difficult to reassemble the hull construction if the timbers were taken apart for conservation or any other reason. For that reason the committee recommended that the Vasa should be kept in one piece as long as possible and only taken apart “if it is found that the tension cannot be controlled, which might mean that parts that were too badly distorted would have to be remade from new material". The recommendation from the Vasa committee was that all the strengthening needed was to be put into her as soon as it was possible to get to the Vasa hull.

The iron bolts had rusted away almost completely and should be replaced to strengthen the hull. Therefore as many ordinary iron bolts as possible with a diameter of 3/4" were inserted by the divers to keep the hull construction together during the lifting. For this, the original bolt holes were used. In the bottom of the hull and in other places where there was not enough room to handle the bolts, the bolt holes were plugged with cone-shaped wooden plugs to make the hull watertight.

As the whole of the stern part had fallen away, this was repaired with planks to make it possible for the pumps to keep the hull floating during the transportation into the dry dock (figure 3-2). New gun port shutters of solid wood were constructed. Each of these was padded to fit exactly and sealed with leakproof fabric on the inner side. The temporary gunport shutters were put into place by the divers and secured with T-headed bolts.

Interior reinforcement of the construction in the middle portion of the hull was provided in order to secure the hull during the lifting procedure.

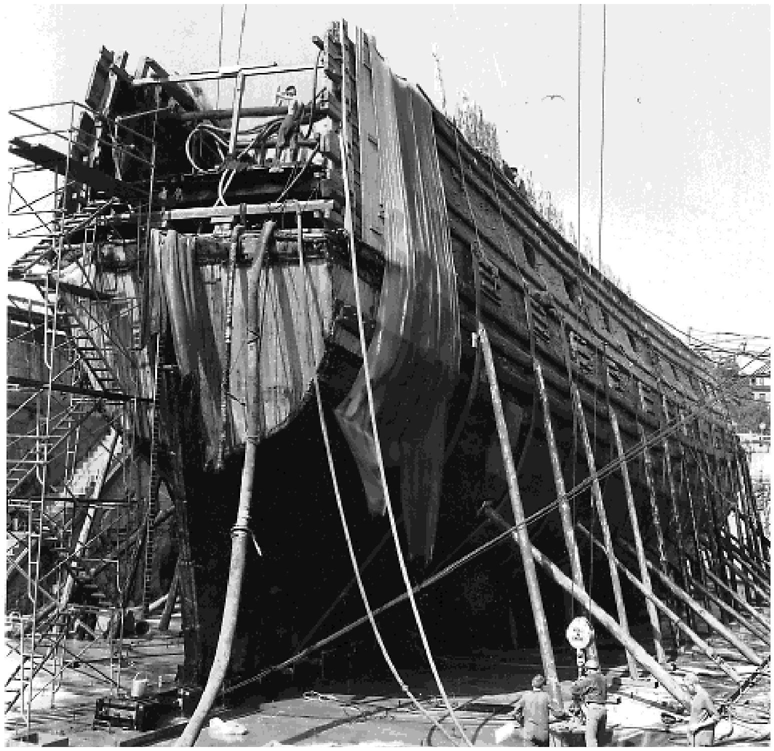

Figure 3-2 The Vasa hull on the pontoon in the dry dock (photo from the archive of the Swedish National Maritime Museum)

Protecting the Hull from Drying

As soon as the ribs of the hull started to emerge from the water during the lifting procedure there was a threat that the wood might dry to a point where there would be damage. To secure surveyance of the emerging wood, Lundvall was stationed on the lifting pontoons during the whole period of the final lifting. Early on the first day of lifting part of the broken main mast, two stanchions with sculptured heads and about half a meter of the ribs were above the surface of the water. It was decided that those parts were to be covered with plastic sheets on the following day. This was done on the morning of the second day by Lundvall in a small rowing boat. Before being covered, the wood was sprinkled with sea water because the surfaces had already begun to dry.

It was assumed that merely covering the wood would not be sufficient to keep it from drying. Tore Boström, who was then manager of the storage and conservation of the Vasa material, had therefore designed a watering equipment for the occasion. It consisted of a total of about 100 metres of aluminium pipes, two inches in diameter, that were mounted together with joints to fit the shape of the railing. The pipeline was perforated with a number of holes 2 mm in diameter at distances of 50 mm from each other along the whole of its length. On the evening of the third day, Lundvall together with Göran Bergengren, who held the position of archaeological works manager for the excavation of the underwater site, rowed out to the lifting place and started to install this equipment along the top of the uppermost wale on each side of the hull. The installation was completed on the morning of the fourth day of the final lifting.

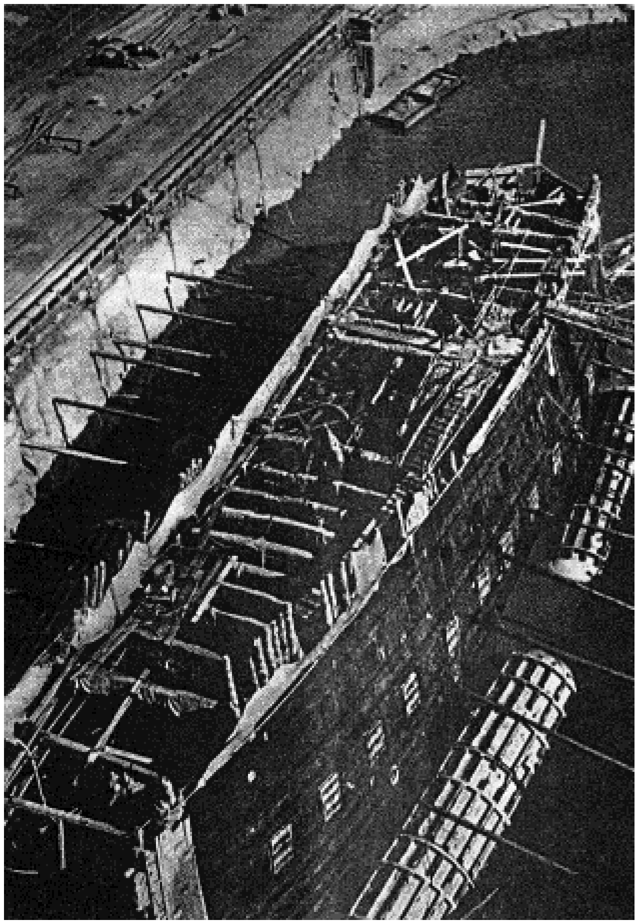

Figure 3-3 The Vasa hull arrives into the dry dock with the aid of lifting pontoons (photo from the archive of the Swedish National Maritime Museum)

Some garden sprinklers were used for sprinkling the few separate items that had emerged, like the main mast and the two stanchions with sculptured heads, and to feed these a main pipeline was mounted from stem to stern inside the hull. The pipeline system was connected to a pump that was placed at the stern of the hull with the pipelines ending at the fore end. During these first few days, only seawater was fed to the system.

As soon as it was possible to get down to the upper gundeck, which had to be done when the hull was still at sea, the installation of a pipeline for waterspraying was continued on the level of the lowermost side of the beams of the upper deck. As there was no time for actual calculations, the choice of pump was made somewhat at random. When its function in the watering system was tested, it was realized that the capacity of the first chosen pump was too low and it was replaced with a pump of higher capacity (158). Because the spray of the watering system had to be rather feeble so as not to harm the soft surface of the wood, the wooden surface could not be kept continuously wet by mere water flow. However the fact that it was mounted inside the plastic sheet wrapping enhanced its watering capacity.

This watering system kept the wooden surfaces that protruded above the surface of the sea wet until the Vasa hull was brought into the Gustav V dry dock, which was achieved on the eleventh day of the lifting procedure (figure 3-3).

The Pontoon

In its final report, the Vasa committee considered some alternatives for the future of the Vasa. One idea was to construct a museum building somewhere, dismantle the hull and reassemble it in the museum. Another idea was to build a slip and pull the Vasa into a nearby building especially designed to house her. A third idea was to take the Vasa hull into a dry dock and construct the museum building over the dock. The committee recommended the third idea and also indicated the dry dock that was most suited for the purpose, the dry dock of the galley dockyard ("Galärvarvsdockan").

On 26 November 1959, the Board of the Vasa took up the question of the dry dock and decided to request the dry dock of the galley dockyard from the government for the purpose of storing the Vasa hull. At the same time, workshops for storing and treating material from the ship were also requested (62).

Construction of the Floating Pontoon

At their first meeting, the Board of the Vasa had taken a decision in principle that the Vasa hull was to be lifted with a floating dock as being the best alternative for the archeological excavation (61). A design for a floating dock was ordered (159) and a syndicate of four companies (160) was willing to build the lifting dock as a joint venture at cost price. Work on the lifting dock project went on for some time, but after a while doubts began to grow about the feasibility of the project. Clason reported to the Board of the Vasa that representatives of the salvage company (155) had declared at a meeting on 8 March 1960 that they were unsure about the stability if a lifting dock was used and that they would prefer to use lifting pontoons instead (63). This meant that some reinforcement had to be made midships inside the hull, which might cause some disturbance of the archaeological layers in that area. The decision was to take the advice of the salvage company to follow a conventional salvage procedure for the Vasa hull.

However, at the meeting of the Board of the Vasa on 28 September 1960, Franzén suggested that a floating dock should be kept as a standby at the final lifting to be of help if unforeseen complications were to occur. He also gave his opinion that a floating dock would be the most suitable place for keeping the Vasa during the winter of 1961 - 1962. The board therefore decided to investigate the possibility of acquiring a floating dock for the purpose (64).

After discussion about the technical possibilities of moving the Vasa hull on to a floating dock, Clason came to the conclusion that it would be possible to take away the walls of the floating dock and construct a floating pontoon instead. It would then be possible to place the pontoon on the floor of the large GV dock and thus leave a sufficient depth of water to float the Vasa hull into the dock and put it down on the pontoon. Clason presented his idea in a memorandum dated 21 November 1960. Synnelius, who was head of the construction department of the Board of the Vasa, had also come to the conclusion that such a procedure would be possible and he presented a plan at the Vasa Board meeting on 24 November.

Clason´s memorandum was also brought to the attention of that meeting. The Board took a decision to act according to the new plan (30, p 4).

The same company (159) that had previously been in charge of the design of the lifting dock now received the new assignment to design the pontoon. The same syndicate (160) that had previously been commissioned to build the lifting dock was now to build the pontoon. The dimensions of the pontoon were calculated to 50 x 20 x 5 metres and it would contain a number of trimming tanks for stability (31).

The first idea had been to build the pontoon at the Naval dockyard. However, the Naval dockyard had no dry dock free at the time when the construction of the pontoon had to be started in order to fit into the schedule for lifting the hull. Another dockyard to the south of Stockholm had an idle dock at that time, but there was insufficient depth of water to transport the finished pontoon from the dockyard. After some investigation, Gävle dockyard made their new floating dock available free of charge. The final design was a pontoon with two rows of ten paired tanks. It measured 56 x 21 x 3,75 metres (7, p 112) and was made of iron-cord-reinforced concrete.

The finished pontoon was towed in the floating dock from Gävle to Stockholm, a distance of 150 nautical miles. It arrived in Stockholm and was taken into the GV dock on 28 April 1961 (7, p 15).

Vasa on the Pontoon

The Vasa hull was floated into the GV dry dock on 4 May 1961. The dock was emptied and the hull was put down on the pontoon on 17 May. The pontoon was then emptied of water and it rose with the hull standing on it when the dock was again filled with water.

As soon as the hull was in position on the pontoon, the whole of the exterior was exposed to the weather. This meant that there was a need for effective watering of large surfaces. To meet this need, another system of pipelines was placed at a somewhat lower level on the exterior. This made automatic watering of the exterior possible down to the level where the hull curved inwards to reach the keel. The lower surfaces that were not in the watering zone of this equipment were sprayed with water by hand using a firehose several times during each day and also a couple of times at night. As there was access only to sea water at the lifting site, this was used in the system that was first installed. The use of sea water had to be continued even when the Vasa hull had arrived in the dry dock because the large amount of water needed for the watering could not be provided by the wharf's water system.

Even the inside of the hull needed watering to keep it wet, so another system was constructed that created a water flow from the top of the ribs. This type of installation was repeated on the upper and lower gundecks where pipelines were fitted on the lower side of the deckbeams near the inner planking on both the starboard and portsides. On the orlop deck and in the hold, both of which were closed compartments that had very little connection with the outside atmosphere, there was no need for waterspraying.

The interior watering system soon had to be supplemented by garden-watering sprays on the decks. This system was flexible and was rearranged from time to time when new surfaces came to light during the excavation work. In the interior watering system, fresh water had to be used because the interior of the hull was the working place of the archaeologists.

The Excavation of the Vasa

The need for an archaeological expert to ensure that the archaeological aspects were taken into account when decisions were made concerning the salvage and to act in the future as leader of the excavation of the Vasa hull was on the agenda of the Board of the Vasa as early as their second meeting. This led to the appointment of archaeologist Hans Hansson from 22 January 1960. When he later became director of the maritime museum he was given a permanent seat on the Board of the Vasa in that capacity, and Per Lundström was taken on as archaeologist from 1 November 1960.

As early as 31 October the same year, a plan for the excavation of the Vasa was put forward. It was signed by Per Lundström and Hans Hansson together. After some adjustments, the plan was approved by the Board of the Vasa and permission was granted to purchase material and hire staff for the excavation work. On 18 May 1961, Lundström reported back to the Board that the excavation work had started on 25 April. That was the day after the Vasa broke the water surface (67).

At the meeting of the Board of the Vasa on 3 June, Lundström reported that 100 cubic metres of silt and clay had been removed from the upper gundeck and that this had contained 5000 objects. The excavation of the 250 - 300 cubic metres of silt on the lower gundeck had been started and preparations for removing the ballast had been made.

On 9 November, Lundström reported to the Board of the Vasa that the excavation had been finished on 29 September. The registered finds mounted to about 14 000 pieces (69).

Reinforcement of the Hull

On 1 September 1961, Cronvall, who had been appointed works manager of the working site "the Vasa pontoon" for the period from when the pontoon left the GV-dock until its arrival at the temporary Vasa museum site, reported to the Board of the Vasa that the reinforcement work that had started before the hull was lifted had been continued. One thousand temporary 3/4" iron bolts had been put into the hull and Cronvall estimated that a couple of thousand more were needed (68).

To secure the construction, four large steel bars with a diameter of 1.5" were drawn across the hull from starboard to port at the level of the upper gundeck. To fasten these bars, new holes were made in the planking in the middle of the space between gunports of the upper gundeck. Around the newly made holes the outer planking was protected by short U-irons. Both ends of the bars were threaded and secured with nuts on the outside of the planking (9, p 131). In addition, the stern and also the foremost part of the hull were secured with smaller bars.

Supporting the Hull on the Pontoon

The first exterior supports for the hull on the pontoon were the props against the sides of the dock (figure 3-3). To be able to build the pontoon superstructure, the supports for the hull had to be placed on the pontoon. To support the huge hull construction, two rows of props were placed along the sides.

Figure 3-4 Props supporting the Vasa hull on the pontoon (photo: Gerhard Bauer)

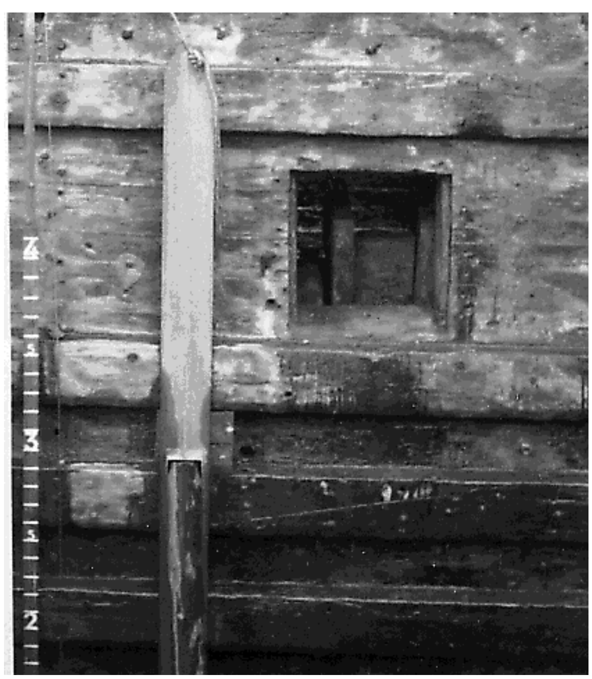

Figure 3-5 Detail of construction of the fastenings of the props (photo: Gerhard Bauer)

The upper row of props reached about six metres above the roof of the pontoon. To enable the props to provide support without damaging the wood, their ends were put into special constructions in the shape of caps mounted on broad steel bands.

There were ten such steel bands hooked into loops mounted in the roof of the pontoon on each side of the hull with their ends reaching to the lower gunports at either side of the hull (figures 3-4 and 3-5).

The caps for the ends of the props were situated at the height of the second wale below the gunports of the lower gundeck. The assembly of supports and the steel bands thus created a kind of cradle for the hull.

The lower row of props was put against the lower side of the lowest wale in a conventional manner.

Construction of the Superstructure

Before the pontoon left the dry dock on 26 July 1961, the prefabricated beams of pretensioned concrete that were to be the support for the walls of the pontoon superstructure were lifted onto the pontoon and fastened (figure 3-6).

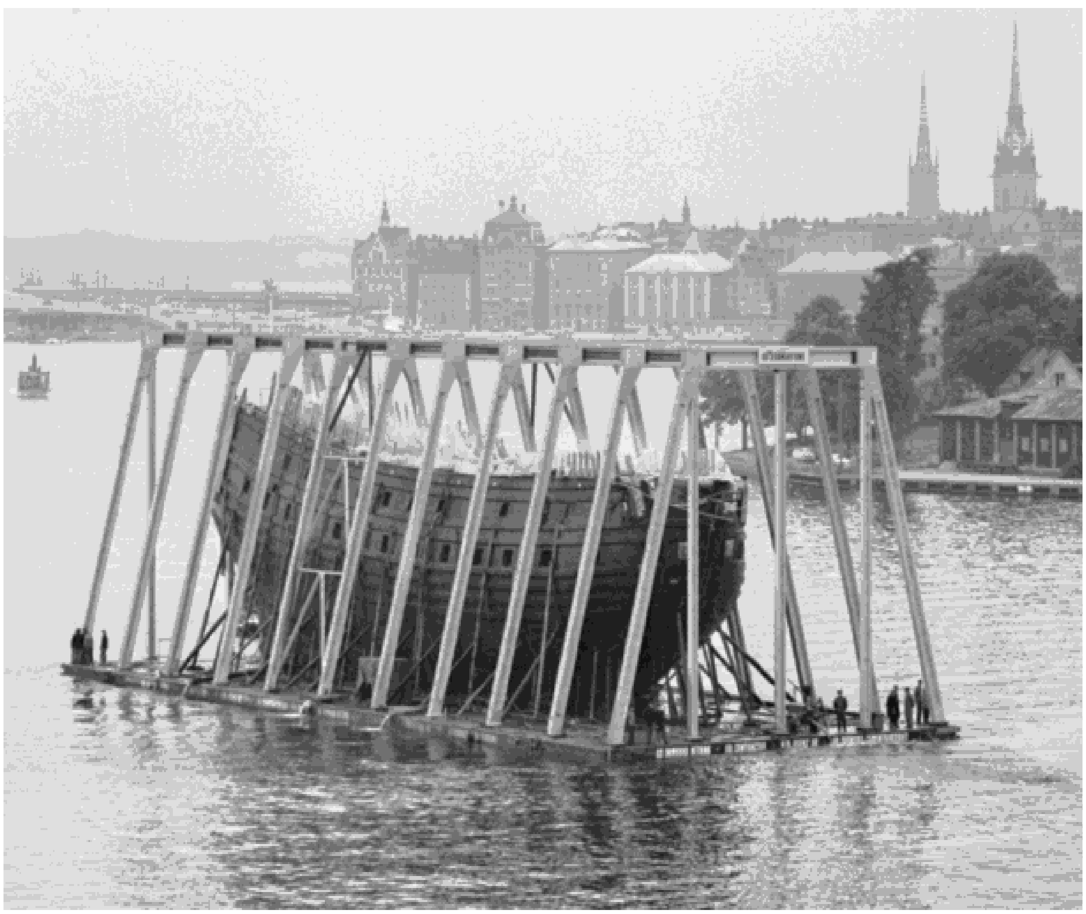

Figure 3-6	The pontoon with the concrete beams leaving the dry dock (photo from the archive of the Swedish National Maritime Museum)

To be as light in weight as possible, the pontoon superstructure was to be made of aluminium sheets. For insulation, ten centimetres of rockwool was mounted between the two aluminium sheets that composed the wall construction. After the pontoon had left the dry dock, it was moored at the quay at the naval dockyard where as much of the protecting superstructure as possible was finished in order not to put safety at risk during the transportation to the chosen site for the pontoon and the temporary Vasa museum. The transportation took place on 23 November, and the pontoon was then moored at the site where the temporary Vasa museum was under construction (figure 3-7). The museum was called "Wasavarvet", meaning the dockyard of the Vasa, to emphasize that it was a working place for the conservation of the ship and also that it was not the permanent museum building (figure 3-8).

Figure 3-7 The Vasa pontoon with the superstructure approaching the museum site (photo from the archive of the Swedish National Maritime Museum)

There were two ways of reaching the pontoon superstructure. The entrance intended for the museum visitors consisted of a gangway that connected a staircase situated on the museum yard with the lower visitors' gallery inside the superstructure about five metres above the roof of the pontoon. The other connection was via the upper surface of the pontoon. It consisted of a bridge that was fastened onto the roof of the pontoon at one end with the other reaching to the backyard of the Vasa museum site. The pontoon superstructure had four gates on this level that were intended for materials and the handling of equipment and installations. The gangway leading to the visitors' entrance had three pairs of doors so as to create one large "lockage chamber" and a smaller one to keep the outside atmosphere from entering the interior of the pontoon superstructure. The other doors were used only by museum staff, who had strict orders to manage the opening and closing so as not to disturb the climatic situation in the pontoon superstructure. The pontoon superstructure was closed with walls and a roof was completed on 16 December 1961.

Discussions had taken place about the advisability of putting windows in the façades. The conclusion was that, provided material was used that did not transmit UV-rays and provided no sunshine would fall on the Vasa, there was no objection to windows (79). That part of the wall of the superstructure below the visitors’ entrance which was facing land was therefore constructed of large windowpanes. There was also a row of windows along the lower visitors´ gallery in the façade facing the sea. However, the wall of the superstructure facing land was exposed to the morning sun as it was facing almost exactly towards the east and the wall facing the sea was facing west and was exposed to the afternoon sun. The large windows in the eastern wall were therefore painted grey and the lower parts of the windows in the western wall were covered with wooden sheets while the upper parts were painted with a UV-absorbing product and curtains were provided to be drawn when necessary.

Figure 3-8 The temporary vasamuseum "Wasavarvet" that was open to the public 1962 - 1988 (photo from the archive of the Swedish National Maritime Museum)

Vasa in the Superstructure

The pontoon superstructure was first and foremost designed for the spray treatment of the Vasa hull. The narrow space around the hull was functional for that purpose.

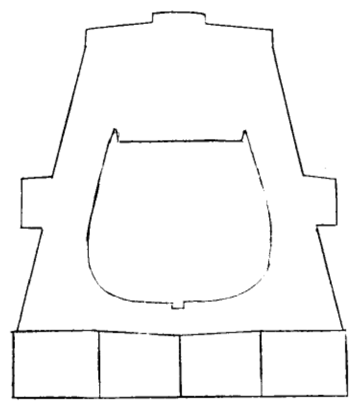

Figure 3-9 The contour of the Vasa hull in the pontoon superstructure, transverse section

The contours of the walls and the roof of the superstructure followed the contour of the hull. The volume of the superstructure was nevertheless 15 000 cubic metres.

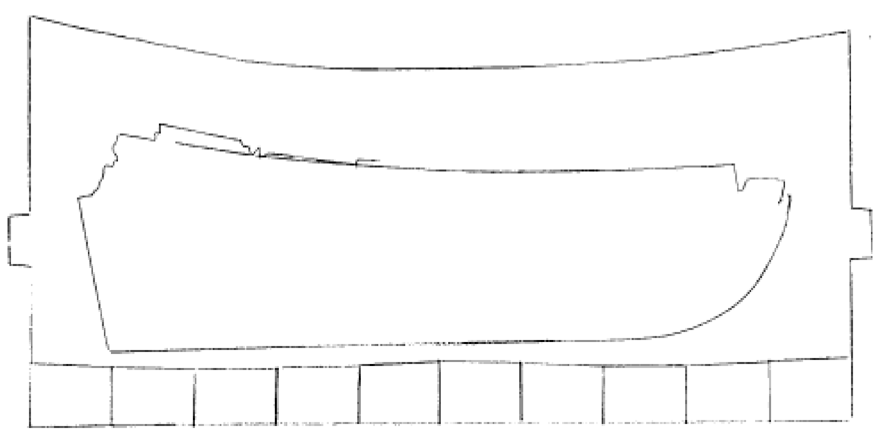

Figure 3-10 The contour of the Vasa hull in the pontoon superstructure, longitudinal section

The superstructure was equipped with two visitors’ galleries. The lower gallery which was connected with the entrance gangway is visible as a projection around the superstructure. The upper visitors’ gallery was contained inside the building (figure 3-9 and 3-10).

Cleaning the Hull

At the meeting of the Conservation Council on 26 September 1961, a detailed plan for the work on the Vasa was presented by Schoerner, Svensson and Barkman. The plan was divided into three parts namely "preliminary work", "cleaning and related work" and "conservation and dimensional stabilization work". "Cleaning and related work" had four paragraphs. The first stated that a number of holes 80 mm in diameter were to be drilled in the garboard alternating on the starboard and portsides. The second paragraph dealt with removal of parts of the planking for the cleaning procedure. The third paragraph said that measuring and tagging of the deckplanks should be started without delay. Finally, the fourth paragraph stated that cleaning had to be started using water and compressed air.

The Vasa hull was still under water spray when Sam Svensson who was in charge of the restoration work reported to the Board of the Vasa on 9 November that water had been applied to rinse mud that remained after the excavation. To get the mud-containing water out of the hull, sixty-eight holes had been drilled in the bottom of the Vasa (69).

Not only the spaces visible to the eye had to be cleaned out, but also the hidden spaces between the outer and inner plankings that were occupied by the ribs. On 12 March 1962, Barkman reported to the Conservation Council (86) that the cleaning had started and on 2 May (87) that it had proved necessary to remove a band of deckplanks on each deck along the sides of the hull to make the cleaning more effective. In May 1962 (71), Lundström reported to the Board of the Vasa that some bands of planks of the outer planking had been removed to facilitate the cleaning procedure. At the next meeting (72), he reported that more planks had been removed in order to continue the cleaning of the hull.

The cleaning procedure was still going on in October 1962. At the meeting of the Conservation Council on 8 October, the cleaning situation was penetrated and it was calculated that it would take another year to finish the cleaning. The work was performed by only one team of workers and to move faster, it was decided to request financial support to hire more workers.

The cleaning continued, however, for more than half a year before Lundström finally reported that it would be finished by 15 July 1963 (88).

The Cradle

The untreated steel bands that had been used to support the hull could not withstand the high relative humidity of the pontoon superstructure but started to rust heavily late in the summer of 1962. This would affect the strength of the bands as supports for the hull and also stain the surface of the wood in their neighbourhood. The steel bands were therefore removed in the autumn of 1962 and replaced by conventional propping against the second lowest wale. The propping against the underside of the hull was also extended (7, p 254).

As early as 1 September 1961, Schoerner had pointed out to the Board of the Vasa (68) that the present support of the hull had to be replaced by a more adequate one. To gain some information about the way other museum ships were supported, Barkman and Schoerner went to England to study the "HMS Victory". Referring to this, Schoerner suggested to the Board of the Vasa (70) that a support shaped as a cradle with horizontal bracings should be constructed for the Vasa hull. He undertook to discuss this with a suitable constructor (156) and, at the end of January 1962, he reported a plan for a cradle consisting of horizontal bracing and a number of perpendicular stays. After some adjustments, the cradle was manufactured (156). It was made of steel that had undergone anti-corrosive treatment.

The cradle was mounted in place in the pontoon superstructure between September and the end of 1964 (figures 3-11 and 3-12).

Figure 3-11 Mounting of the cradle in the pontoon superstructure (photo: Göran Sallstedt)

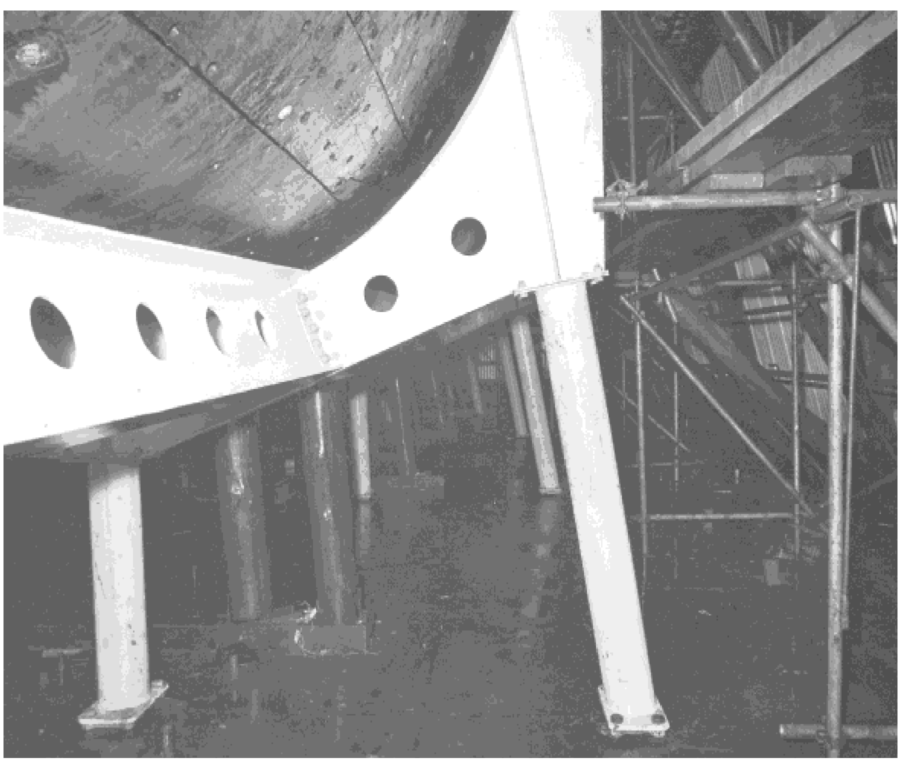

Figure 3-12 The newly mounted cradle showing a gap to the ship´s side (photo: Göran Sallstedt)

Since the exact shape of the shipsides was not known, the cradle was made somewhat wider than would have been necessary. The gap between the elements of the cradle and the ship was filled with units consisting of wedges. To achieve a suitable support for the ship, wedges could be taken away or added to a unit (figures 3-13 and 3-14). Manoeuvering the wedges also allowed for some flexibility when adjusting the position of bolt holes to get a bolt through a series of structural elements (figure 3-15).

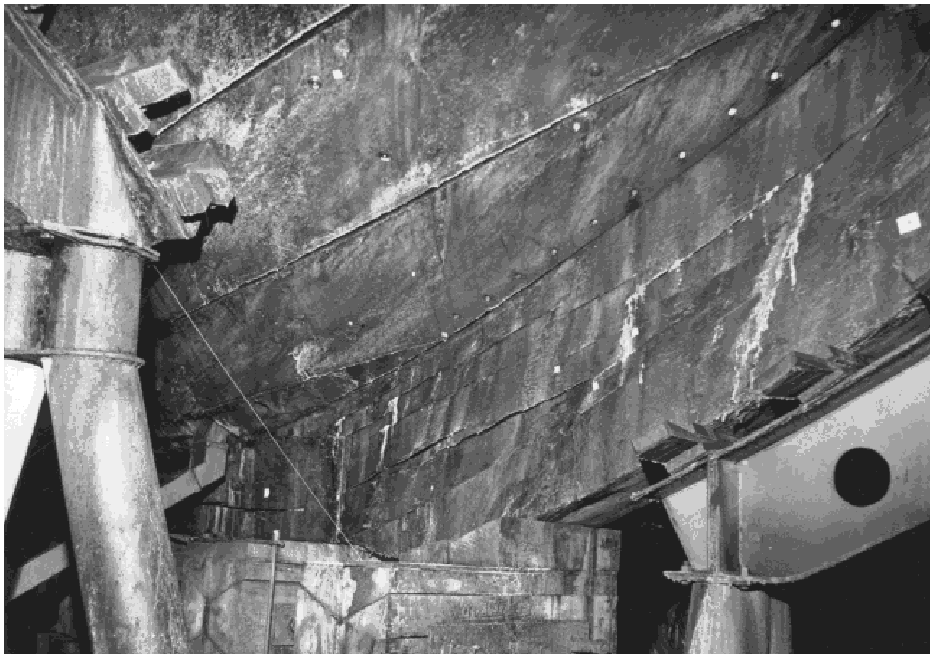

Figure 3-13 The gap between the elements of the cradle and the ship´s side has been filled with wedges (photo: Sven Bengtsson)

Figure 3-14 The supports of the cradle with the units of wedges in the stem and fore part of the Vasa (photo: Sven Bengtsson)

The Permanent Bolting of the Hull

In January 1962, Svensson reported to the Conservation Council (85) that the 3/4" iron bolts that had been driven into the hull had rusted and had to be replaced by permanent bolts of a more durable material. He suggested copper or phosphor bronze. He also pointed out that the skulls of the bolts ought to be shaped in accordance with the period.

To deal with the problem of material, a working group consisting of Barkman, Schoerner and Svensson was formed. Two external experts, Kurt Åkesson, metallographer from the Association of the Swedish Mechanical and Electrical Engineering Industry and Einar Mattsson, head of the Corrosion Section at the Swedish Metalworks, later professor at the Swedish Corrosion Institute were contracted to the group. The working group recommended that tests should be performed with copper and stainless steel. Laboratory tests with the chosen materials were therefore started and a few copper bolts and bolts made of stainless steel were inserted into the hull in the summer of 1964.

Figure 3-15 Inserting bolts into the original bolt holes (photo: Göran Sallstedt)

However, before the tests could show any result, some of the temporary bolts had to be replaced. For this, 7/8" galvanized iron bolts were chosen. To withstand the corrosive Vasa oak, the bolts were painted with an epoxy-paint. It was decided to buy four thousand iron bolts as replacements for the temporary bolts.

In September 1962 (73), Lundström reported to the Board of the Vasa that the work of replacing corroded bolts had been started. He also reported that 8600 bolts made of a durable material were needed for the Vasa hull.

There was a delay in evaluating the copper and stainless steel bolts, and it was obvious that to strengthen the hull a complete bolting had to be carried out with the epoxy-painted galvanized iron bolts. Lundström reported to the Board of the Vasa in November 1963 (74) that, of the 4000 that had been bought, 700 bolts had been inserted into the hull, and that a total of 8000 bolts were needed. The work of inserting these bolts was completed during 1967.

Despite the recommendation by the Conservation Council that stainless steel should be used at least in hidden places, the only stainless steel bolts in the hull were the test bolts. For screws for fastening the deckplanks, however, the chosen material was stainless steel.

Repair of Broken Beams of the Upper Deck

Although the Vasa hull was fairly intact, a large portion of the upper deck had disappeared and there was some damage to the deckbeams of the upper deck. As a rule, repair of the original material was preferred but seven of the beams were considered to be in such a bad condition that they had to be replaced. Therefore in 1965 seven new beams of pine were ordered from a lumber yard to replace seven of the original oak beams. These new beams were to be treated with polyethylene glycol like the originals, so they were put into a conservation tank together with original Vasa material.

Because the conservation programme was designed to suit the original material, the process took longer than a year. In that period of time, there was some rethinking about replacing any original beam, so repairs were made instead by inserting lengths of steel T-iron into the broken deck beams.

Enlarging the Pontoon Superstructure

Reconstruction of the stern was a part of the original programme. It became obvious that to perform this the pontoon superstructure was too narrow and that it had to be enlarged at the rear wall. During the summer of 1966, the reconstruction of the beak-head of the ship had been started, and estimations made it clear that a reconstruction sufficient to make possible the mounting of the figurehead lion would protrude about 6 metres beyond the wall in front of it. This meant that enlargement was needed both at the front and rear walls of the pontoon superstructure. The plans were presented to the Conservation Council at the meeting on 12 September 1966 (91, §3). The meeting was of the opinion that the work on enlarging the pontoon superstructure had to be performed as soon as possible and that it should be finished by the end of 1967 at the latest.

To be able to enlarge the pontoon superstructure, it was necessary to add more stability to the pontoon, and two lifting pontoons were constructed. Lundström reported to the Conservation Council on 12 March 1968 that the two lifting pontoons were ready to be mounted on each of the longsides of the original pontoon (92, §3).

When these two lifting pontoons were in place, the project of enlarging the superstructure could start. The work was carried out during a couple of months beginning in August 1968. It was very delicate work, because the climatic conditions in the superstructure had to be kept stable during the construction period. The new walls were therefore built on the outside before the old ones were torn down.

The enlargement of the pontoon superstructure created enough space to rebuild the stern of the Vasa. The stern of the ship was however badly damaged, in fact broken away from the rest of the hull. A reinforcement of the stern construction was therefore needed. In order to accomplish this, a three-limbed construction was designed with one transverse beam and two beams that were connected perpendicular to the first one about midway between their ends (figure 3-16). The beams were made of stainless steel, 8 mm thick. The tranverse beam was 4250 mm long while the two connected beams measured 5600 and 4500 mm respectively.

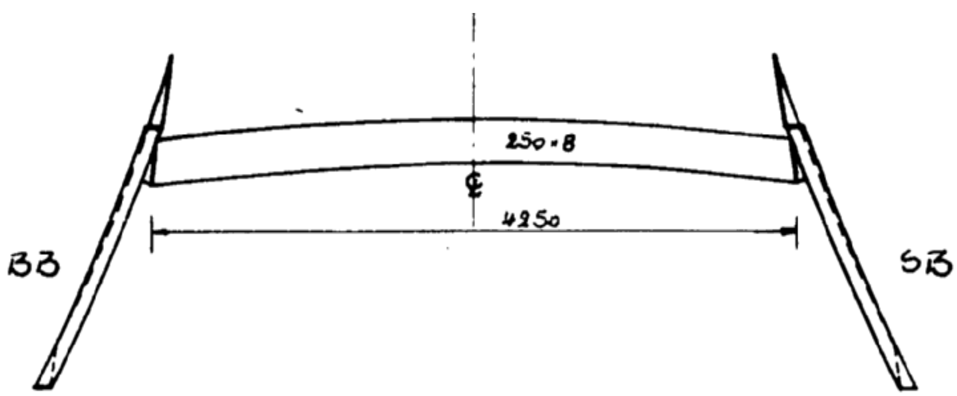

Figure 3-16 Steel construction for reinforcing the stern part of the hull, SSHM, construction drawing No 218, detail, 22-5-1970, E Hoffmann

Two such constructions were inserted from the back, the lower on a level with the upper gundeck and the upper on a level with the upper deck to support the protruding aft cabins.

The starboard and portside leg of each construction were fastened to ribs in the main part of the hull and covered by the outer planking (figures 3-17 and 3-18). Thus the steel constructions create two shelves for the protruding parts of the stern (93).

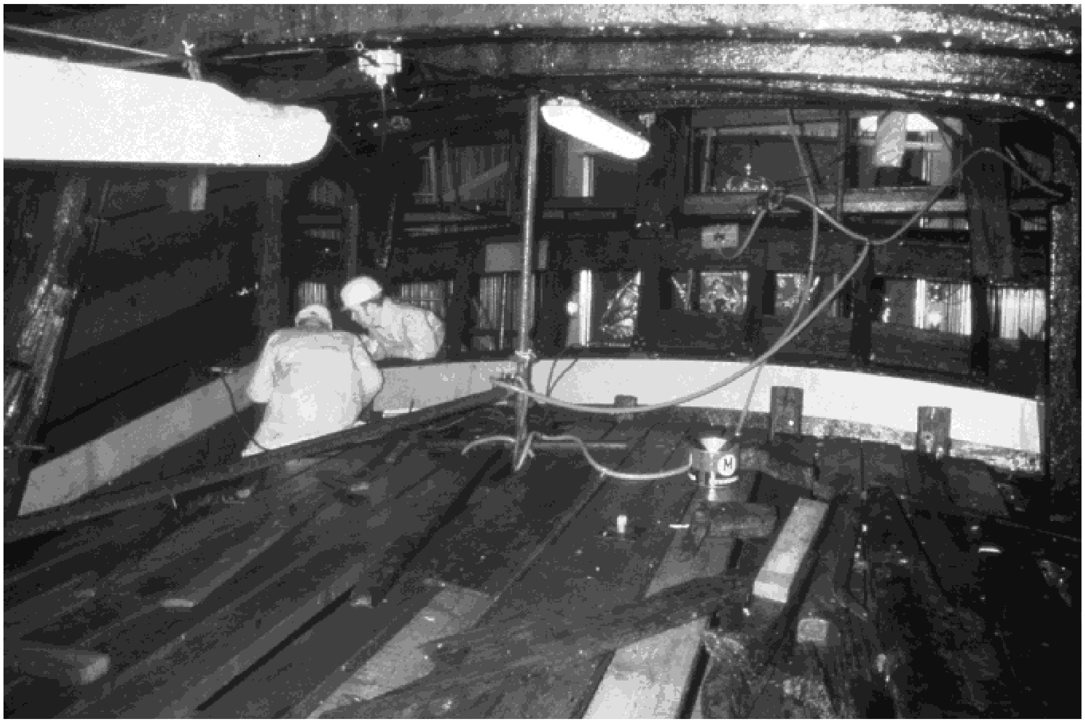

Figure 3-17 One of the steel constructions for support of the stern put into place (photo: Björn Hedin)

Figure 3-18 The steel construction, detail (photo: Björn Hedin)

The beakhead part of the hull that was to be reconstructed also required support. This was accomplished through a hanging support from the roof construction of the pontoon superstructure.

Repair of the Pontoon Superstructure

In 1971, before the installation of an air conditioning system, air leakage of the pontoon superstructure was investigated using dinitrogen dioxide. The leakage was calculated to be 0.45 times/hour in calm weather and 0.73 times/hour when there was a wind of 8m/s.

After the spraying with conservation liquid had been stopped, it was observed that the hull became wet in the autumn. It was noted that there was condensation in the pontoon superstructure and that water was dripping onto the Vasa hull. This made the Conservation Council query the condition of the superstructure and suggest a technical investigation of the building (117, §4). As the underside of the hull also became moist, a preliminary investigation of the temperature situation in that region was performed (123, §6). The investigation showed a climatic situation around the dewpoint and practically no air movement. As a result, the Conservation Council recommended a thorough investigation of the condition of the building. However, plans for a new museum building made the National Board of Building and Planning somewhat reluctant to invest more money than necessary in the pontoon superstructure. To prevent condensation dripping on to the hull, the first suggestion was to hang sheets of canvas above the hull. This was not however done. Instead, the aluminium sheet walls and the concrete beams of the superstructure were painted with water-absorbing paint (125, §8).

However, it was still difficult to keep a tolerable climate in the building, so the museum achieved sponsorship for an investigation of air leakage (157). The investigation was performed in June 1981 and revealed air leakage about double the amount observed in 1971.

Although the government had decided in 1981 that a permanent museum for the Vasa was to be built, there was some delay in carrying out this project. As the bad condition of the pontoon superstructure caused anxiety, the members of the Conservation Council, who felt it their responsibility to point this out, made a statement in November 1983 that either a new museum building had to be guaranteed by 1988 or the pontoon superstructure had to be extensively repaired and insulated, or else the hull had to be taken care of in a way that would not allow visitors (134, §5). In June 1984, the museum director reported that he had been in contact with the National Board of Building and Planning and enquired about the requested investigation of the condition of the pontoon superstructure (137, §7). As the National Board of Building and Planning showed little interest in the pontoon superstructure, the situation was on the agenda of the meetings of the Conservation Council throughout 1985 and at the beginning of 1986. During the autumn of 1986, some repair and insulation work was carried out on the superstructure.

Parallel to this, work on the permanent Vasa museum progressed. The time schedule of 1988 was only slightly over-run. Vasa was moved to the new museum in December 1988. The museum building was completed during 1989.

Rejoining the Sculptural Adornment with the Hull

Although the main idea from the start had been to keep the Vasa hull in one piece during the conservation and drying process, the attached galleries and the sculptural adornment that had fallen off the hull were of no importance for the hull construction. Therefore, there was no need to rejoin these categories of material with the hull at an early stage, and they were treated separately in tanks. This process went somewhat more rapidly than the spray treatment of the hull and at the time when the finishing surface treatment of the hull started, the sculptures were already in equilibrium with the intended final museum climate. This created a difficult situation for the rejoining of tank-treated material with the Vasa ship.

The influence of the outside climate on the climate inside the pontoon superstructure meant that spring was the time of the year that was most favourable for controlling the inside climate. With this in mind, the attached galleries of the aft and stern part of the hull were reconstructed during the spring and early summer of 1979. No sculptured objects were however reattached until more than a year later.

The relative humidity of the pontoon superstructure established a marked gradient with a lower relative humidity high up in the building. To make use of this, the first rejoinings of sculptured material were pieces of the rail. These were fitted in September 1980. To make sure that the tank-treated material would not absorb moisture to any harmful extent, the sculptured pieces were thoroughly observed and one of them was removed regularly for weighing to make sure that it did not gain in weight.

To make sure that this first rejoinment went well, there was a delay until the spring of 1981 before it was followed by the next one. From the autumn of 1981 however, the work of rejoining sculptures was continuous. The first constructions to receive their sculptures back were the sides of the ship. In the period from October 1981 to September 1982, all the lion masks were reattached to the gunport shutters. In Januari 1982, a very spectacular 2.5-metre high statue of a warrior was restored to its position at the starboard bow.

The next part to be reconstructed was the beak-head, with its rows of sculptures along the sides. The rejoining of sculptures was preceded by some strengthening and adjustment work to the beak-head construction itself. The work was concluded in March 1983 with the rejoining of the genuine lion figurehead instead of the plastic replica that had been the beak-head adornment since 1969 (figure 3-19).

Figure 3-19 Rejoining the lion figurehead (photo: Björn Hedin)

The most spectacular adornment of the Vasa ship is that of the stern. The sculptures of the lower part of the stern that have a structural function for this part of the ship were the first items to be refitted when the work started in December 1983. Thereafter it was the turn of the huge amount of sculptures situated higher up on the stern. The national coat of arms with its two lions was the last sculptural item to be refitted in the spring of 1984 (77).

The Transportation Encasement

The permanent museum building site was situated about 500 metres by sea from the temporary museum site where the pontoon with its superstructure was moored. From August 1988, a special encasement was constructed around the Vasa hull. The construction rested on four "towers" made of standard steel elements, placed at each corner of the construction. The walls were built of corrugated aluminium sheeting covered with insulating rockwool (figure 3-20).

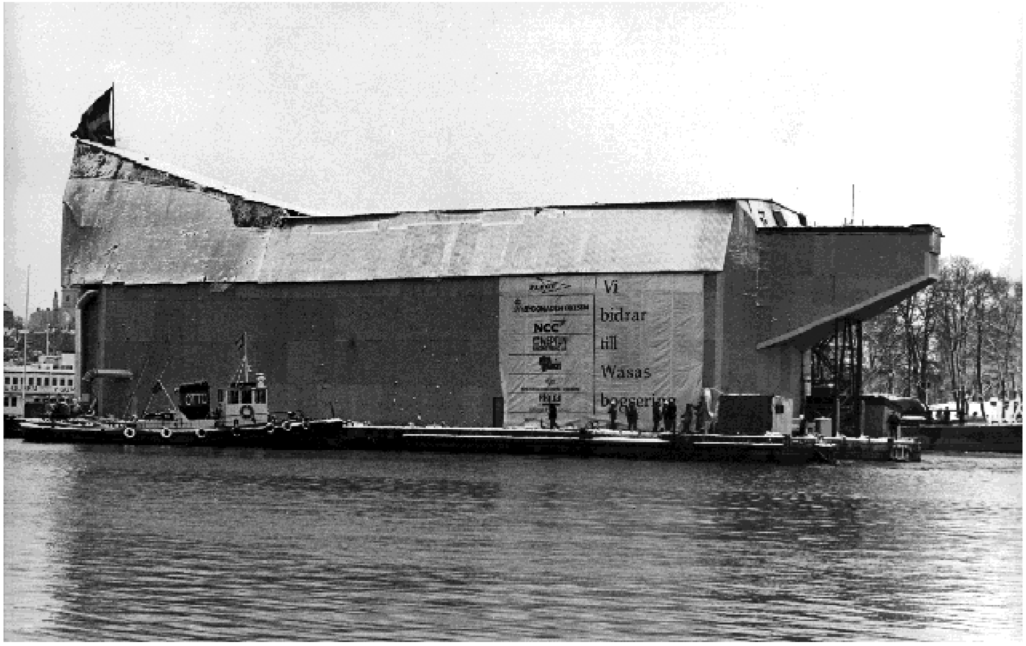

Figure 3-20 Vasa in her transportation encasement moving towards the permanent museum building (photo: Sven Bengtsson)

The side walls stood only 130 cm from the hull at its broadest part. The roof of the encasement touched the railing of the Vasa so there was very little space around her. Nevertheless, it contained all the installations necessary to maintain the climate during the transportation and during the first period in the permanent museum building, before the air conditioning installation of the new museum was put into action.

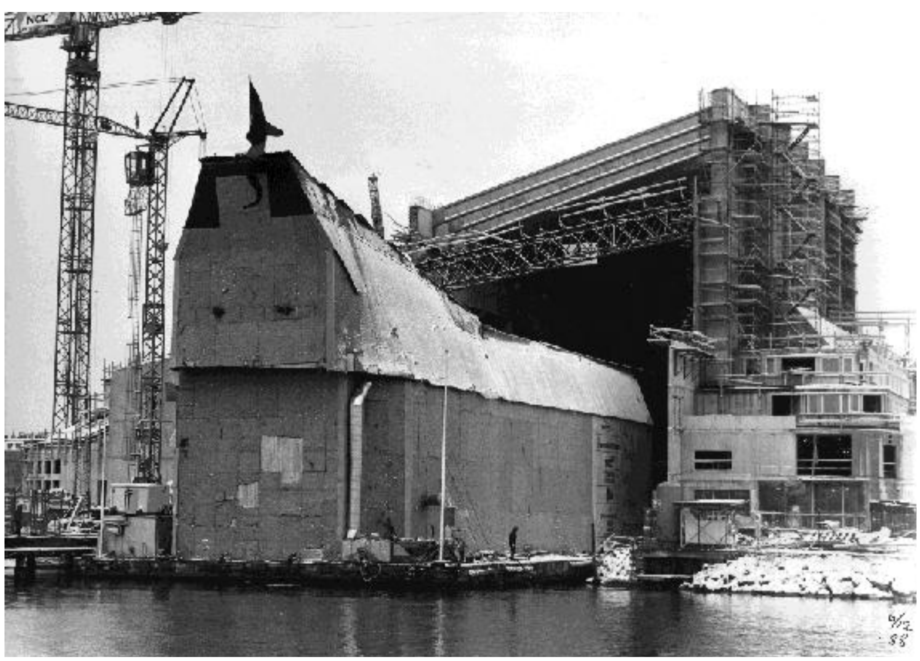

Figure 3-21 The transportation encasement on its way into the Vasa museum (photo: Sven Bengtsson)

The walls of the pontoon superstructure were removed when the encasement was finished, and the concrete beams that had been the framework on which those walls had been constructed were lifted away. Finally the moorings were unfastened and the pontoon was ready to be towed the 500 metres to the permanent museum building.

The Permanent Vasa Museum Building

The permanent museum building into which the Vasa pontoon floated on 6 December 1988 had been under construction since the autumn of 1986. When the Vasa was brought into the museum, the walls of the museum building except for the one facing the water were completed (figure 3-21). After the pontoon had been brought into the museum, the dry dock was emptied and sealed off from the surrounding water, and the final wall of the Vasa museum was built during the spring of 1989.

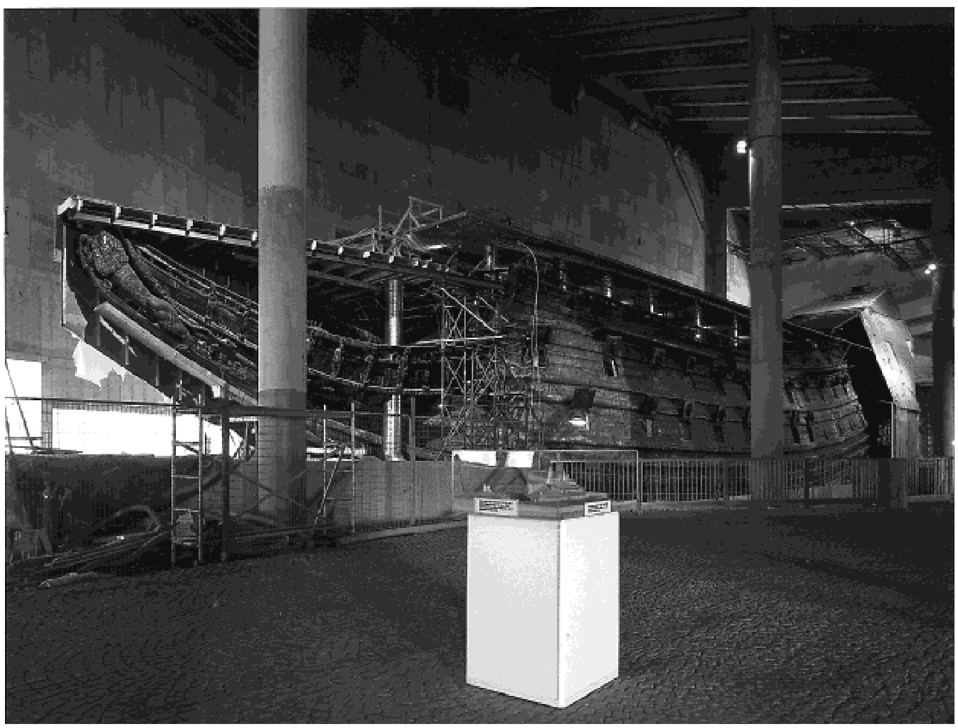

Figure 3-22 Vasa in the permanent museum with part of the transportation encasement still in position (photo: Hans Hammarskiöld)

The Vasa hull remained in its temporary encasement during that period, but at the end of April part of the encasement was removed to allow visitors to see the Vasa at the construction site (figure 3-22). The rest of the encasement was gradually removed during the autumn of 1989.

The museum is an irregularly shaped concrete building that covers an area of roughly 100 by 60 metres with the main directions northeast - southwest, southeast - northwest (figures 3-23 through 3-26). The interior walls have raw concrete surfaces. The windows are scarce and spaced so as to prevent daylight from falling on the exhibits including the Vasa.

All entrances to the museum are constructed as a lockage system with two consecutive sets of doors with a space between them in order that the interior of the museum shall never come into direct and uncontrolled contact with the outside atmosphere. Between the reception space of the main entrance and the museum space there are three consecutive sets of doors so that two "air-lock chambers" are created. Between the office space and the museum space there is always one "air-lock chamber" to pass.

Half the floor area is covered with natural rock stones and half consists of untreated pine wood of very high quality. The part of the dry dock that is inside the museum still has its original rock stone walls.

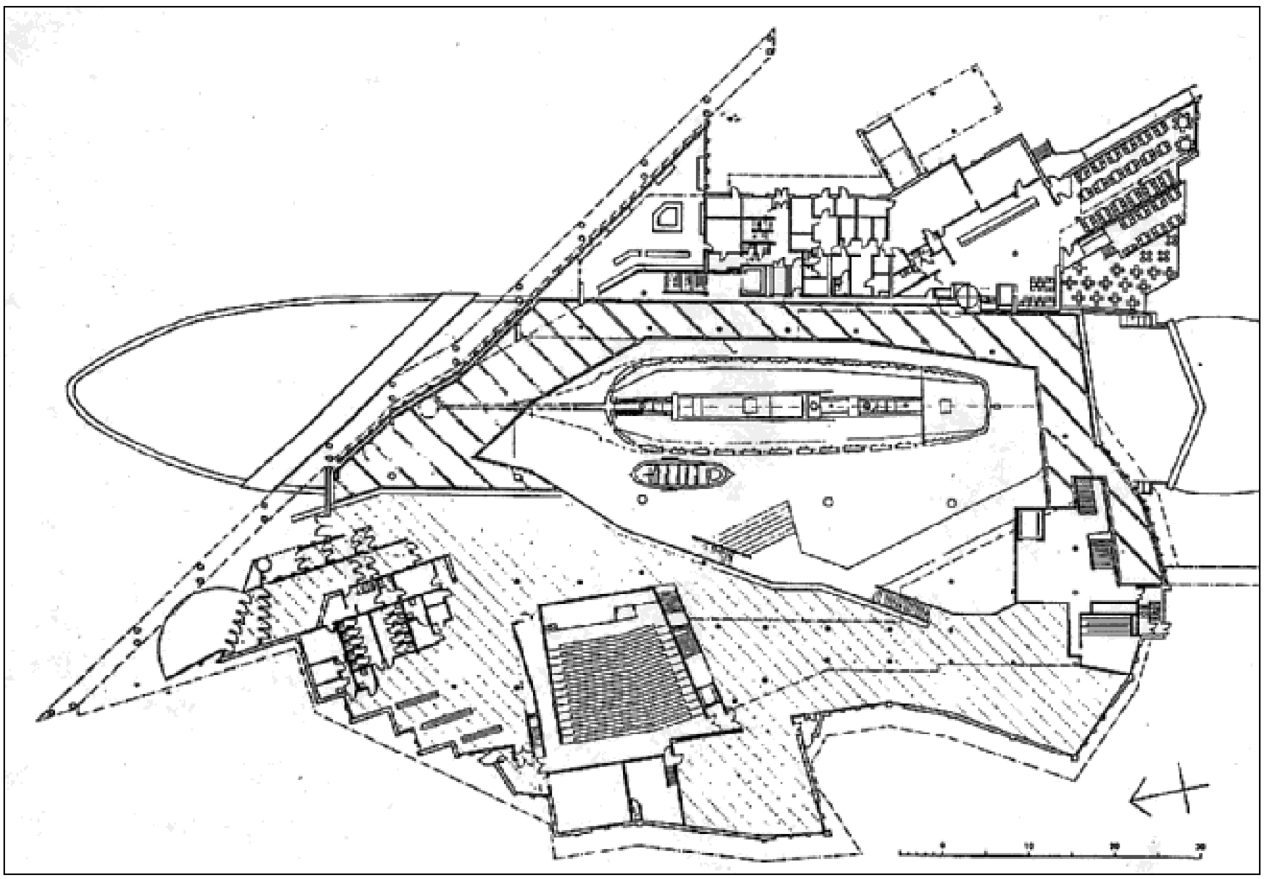

Figure 3-23 The ground floor (entrance floor) of the Vasa museum (drawing: Göran Månsson)

The exhibition space for the Vasa ship and the explanatory exhibitions on the Vasa theme occupy a large irregular continuous space with a volume of about seventy-five thousand cubic metres. About 30 per cent of the total exhibition volume is occupied by the Vasa ship itself that has a height from floor to ceiling of about 31 metres (Figures 3-24 and 3-25)

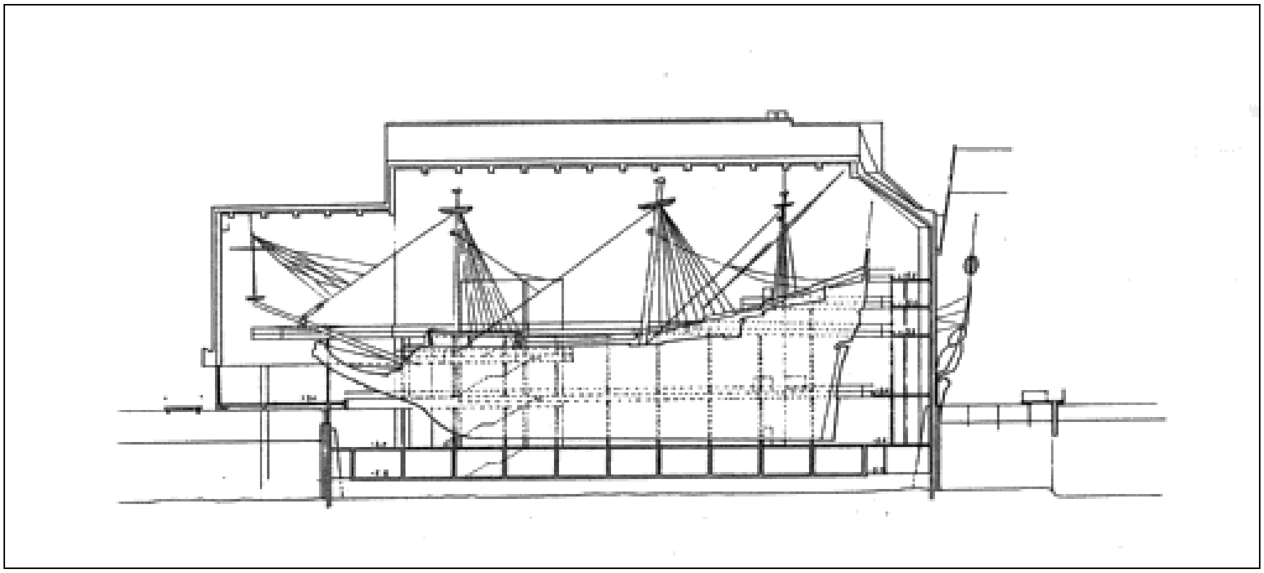

Figure 3-24 Longitudinal section of the centre region of the museum building with the Vasa (drawing: Göran Månsson)

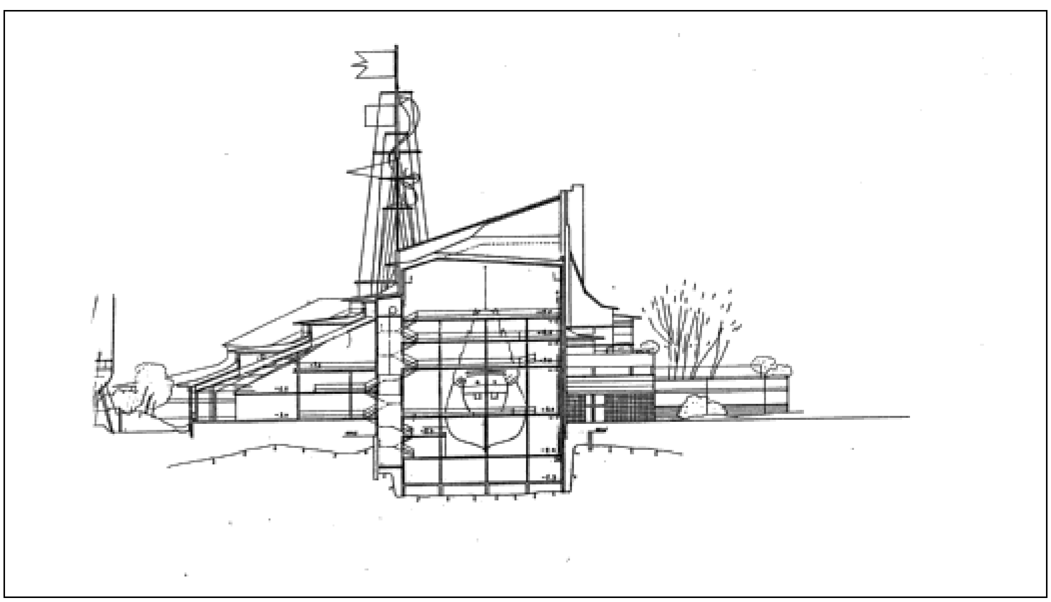

Figure 3-25 Transverse section of the centre region of the museum building with the Vasa (drawing: Göran Månsson)

Figure 3-26 The north-west façade of the Vasa Museum (photo: Sven Bengtsson)

Chapter 4

TREATMENT OF THE VASA

The tendency of the wet Vasa wood to shrink on drying was noted as a fact by the Vasa Committee which says in its final report (24) that "by exchanging water for other bulking substances it is possible to diminish, but not altogether to avoid, changes in dimensions and related deformation" (25). The report says that different treatments are applicable but "for technical and economic reasons, glycerine will be the only possible substance to use for huge dimensions" (26). The method of application mentioned was painting the glycerine onto the wooden surfaces with brushes. When this treatment was finished, a surface treatment with linseed oil was recommended. This procedure was applied to most of the heavy wooden material that was salvaged before and during 1958.

However, another way of drying and stabilizing wet archeological wood was used for a very delicate but apparently unchanged lionmask gunport shutter adornment that was salvaged on 20 September 1957. This was a very early find that was given the number 22 in the find list. It was made of lime wood. Like all the wooden finds, it was treated according to paragraphs Nos 5 and 6 in the instruction (7, pp 273) for registration and taking care of objects from the Vasa. Paragraph 5 gave instructions about how to clean a salvaged object. It was stressed that water had to be used very gently. Brushes and other mechanical devices must not be used without the consent of one of four people: Hansson and Strömberg from the Wasa Committee or the experts Hamilton and Svensson. Paragraph 6 stressed that the salvaged objects could be kept in a dry environment for only three days and nights.

Strömberg felt that this might be too long for the delicate lionmask. It was therefore transported to the conservation laboratory of the National Historical Museum for special treatment. For the preservation, the procedure of extracting the water with organic solvent was chosen. For this purpose a special tank with a lid was constructed, as the organic solvents used were volatile and highly flammable.

The lionmask was rather large. It measured 50 x 60 x 25 centimetres and weighed 13.5 kilograms directly from the sea. The solvents generally used for the extraction of water were ethyl alcohol followed by ethyl ether. However, Strömberg felt that this procedure would be rather expensive because of the rather large dimensions of the lionmask. Referring to Brorson Christensen (5), he made some experiments with acetone as a dewatering agent before he decided to use this for the lionmask. To ensure that the dewatering would be a continuous process, he added some dry calcium chloride to the acetone which dewatered the acetone which in its turn was exchanged for the water in the wood (13). Strömberg points out particularly that, because of the difference in density between the fractions of dewatered and dry acetone, convection currents are created that have an excellent mixing effect on the acetone bath. The dewatering process was followed by a stabilizing treatment with beeswax. The stabilizing treatment was performed by exchanging the acetone for white spirit, an organic solvent immiscible with water, and finally immersing the object in molten beeswax.

The result of the procedure was that the shape and texture of the wooden surface were perfect even though the colour was a little dark. The weight of the sculpture after stabilization was about 4.5 kilograms. Assuming zero moisture ratio at this point in time and no filling material residue, this meant a moisture ratio before treatment of 200 %. If instead and more likely, about one kilogram of filling material residue is present after treatment, the moisture ratio before treatment is calculated to be about 285 %.

Even with this successful conservation treatment for one special piece, the need to be able to treat a large number of objects at the same time at a much lower cost was apparent for the Vasa finds. A major drawback of the glycerol/ linseed oil treatment suggested by the Vasa Committee was that it made the objects hygroscopic and thus unstable in the surrounding climate. This made those responsible for the find look for another way of preserving the wet wood. Their primary concern was the sculptured adornments.

In the fall of 1958, Arne Strömberg, who as conservator of the National Board of Antiquities was responsible for the conservation of the Vasa material, suggested that polyethylene glycol (PEG) should be used for especially delicate objects (7). As conservator, he was familiar with the work that had been done with this substance by Bertil Centerwall at the historical museum in Lund. The polyethylene glycol chosen was the fraction with a mean molecular weight value of 4000. The solubility of the substance in water was as high as about 50% at room temperature and its hygroscopicity was very low at the relative humidities that are normal indoors.

The recommendation was that Clason should contact Mo och Domsjö AB in September 1958 to obtain a sample. The PEG was applied both in baths for the smaller sculptured finds and by brushing a solution of PEG in water or ethyl alcohol onto the surface of the object. The use of PEG had been patented by Mo och Domsjö AB and B Centervall. Clason however obtained written permission dated 9 February 1959 to use the "polyethylene glycol method" for the Vasa material without the obligation to pay a licence fee.

This made it possible, as early as February 1959, to put some twenty sculptures, some of them newly salvaged, on exhibition in the National Maritime Museum. Clason wrote (6) "the artefacts needed continuous looking after and now and then it was necessary to set in surface treatment with polyethylene glycol and hot air". The exhibition continued until September 1960.

Clason also stated that "during 1958 we used polyglycol for all artistic (wooden) objects. Planks and the like were, on the other hand, treated with glycerol and linseed oil. During 1959 we have - with some exceptions - used only polyglycol". This statement establishes the polyethylene glycol 4000 as the substance chosen for the disconnected wooden Vasa-finds that could be handled.

Choice of Preservation System for the Hull

The preservation of the hull was mentioned for the first time by the Board of the Vasa at their second meeting that took place on 26 November 1959. At that meeting, the Chief Custodian of National Monuments, Bengt Thordeman, who was a member of the Board said that "the preservation methods that had been tested up till that point in time were not absolutely reliable. The Institute of Wood Research needed time to develop a method that might prove practicable, and this made a delay in the lifting programme for the hull quite acceptable". The main concern of the Board of the Vasa at that time was the lifting of the hull, but the preservation was also a continuing issue and, on 18 July 1960, the technical section of the Board of the Vasa in the first item of the first paragraph of its instruction, together with four other items, received the assignment to preserve the hull and loose parts. The first item of the sixth paragraph lays the responsibility for the planning and execution of the preservation work on a specially appointed conservation expert.

The importance of co-operation with the salvage company (153) so that the continuously updated salvage plan could be put into action is also stressed in the instruction. This came into play on 28 September 1960 when the Board of the Vasa (64, §7), acting on information from the salvage company that the final lifting of the Vasa hull was planned to take place during the last week in May or the first week in June of the following year gave instuctions to the technical section and especially to Mr Boström on behalf of the conservation department, to Mr Hansson on behalf of the archaeological investigation, to Mr Synnelius on behalf of the construction department and to Mr Blenner on behalf of the public relations department to deliver full programmes for measures within the areas of their specialities to assure the feasibility of the salvage programme. The plans were to be presented to the Board at their next meeting at the latest. The answer from the conservation department was delivered (65, §7) by Mr Birkner who was a member of the conservation consultants group. He referred to a memorandum by the conservation consultants group and gave their opinion that the salvage operation time schedule could be maintained.

The schedule was confirmed by the salvage leader, Axel Hedberg to the Board of the Vasa at their meeting on 18 April 1961 (66, §34). He stated that the final lifting of the hull was to take place on 24 April. This led Hans Hansson, who was head of the museum department that was also in charge of the conservation according to the organization plan, to make a statement about the difficulty of the conservation situation because the hitherto conservation project leader, Tore Boström, was leaving his post. He suggested that a number of specialists should be attached to the conservation department and that Lars Barkman, M.Sc., should be appointed head of the department on a full-time basis. The specialists mentioned were Professor Bertil Thunell (wood), Professor Erik Björkman (wood), Tore Boström (metal, glass, ceramics), Hans Holmgren, M.Sc. (wood), Hans Axelsson (textile, leather), Professor Ernst Abramson (food) and conservator Arne Strömberg, the National Board of Antiquities.

The formation of the suggested group of counsellors was decided upon by the meeting, and Hans Hansson was appointed chairman of the group which was called the Conservation Council.

Work by the Conservation Council

On 4 May 1961, the very day when the Vasa hull was brought into the dry dock, the Conservation Council had its first meeting. The conservation of the hull was, of course, the most urgent task and the issue raised by Barkman of ongoing surface cracking on the Vasa hull, that was now in a delicate position with large parts of the wooden surfaces exposed, made it clear that immediate action had to be taken. Since there was information that a quantity of 100 kilograms of polyethylene glycol 400 had been delivered (32), the Conservation Council decided to try this as a remedy for cracks in the surface of the wood. The recommended mixture was 40% by weight of PEG 400 and 3% by weight of sodium pentachlorophenate (152) in aqueous solution. Barkman gave his report at the next meeting that was held on 29 May. He said that the treatment gave no apparent improvement of the surface crack situation, although he had no untreated surface for comparison because he wanted to cause as little damage as possible to the hull. The overall judgement was that the PEG 400 was not very effective against surface cracking (79).

That the preservation and drying of the hull was a process that would take many years was already evident. The main task for the newly established Conservation Council was to find a suitable substance for conservation and a suitable way of applying that substance to the hull. An inventory of possible formulae was started by Strömberg, who handed over his paper about the conservation of waterlogged wood to the specialists at their first meeting. At that meeting, a method of slowing down the drying rate by applying a coating of a special glue to the surface of the wood was presented (78). The Conservation Council member, Holmgren, was assigned the task of looking into the possibilities of such a procedure.

At the first meeting, the three wood specialists, Thunell, Björkman and Holmgren, were given a special assignment of studying the preservation of the hull. The problems to solve were protection against microorganisms and fungi, dimensional stabilization for the long-term conservation of the hull and a suitable way of application.

Choice of Preservatives

The view on the matter of preservatives was that it would not be possible to find a new preservation formula, but that it was necessary to select the best of those already developed (79). The Conservation Council therefore started by inviting specialists and representatives of companies dealing in chemicals used in wood preservation and museum representatives from museums with some experience in the preservation of large waterlogged wooden artefacts.

Protection against Microorganisms and Fungi

The Conservation Council selected preservatives containing borate, pentachlorophenol, and fluorine compounds and arsenic to be investigated. At their third meeting, a combination of boric acid and sodium borate was presented by Mr J Thornton from Borax Consolidated Ltd, London. The product was called TIMBOR. He stressed that the high water content of the Vasa wood made application easy. As a less favourable characteristic, he admitted that mould could occur on the surface of the wood despite the use of borate.

Pentachlorophenol (PCP) was put forward by the council member Björkman and, at the sixth meeting of the Conservation Council, two speakers presented their PCP-formulae. Dr Ragnar Winbladh from Centralbolaget för Kemiska Industrier AB presented what he called the "Hylosan principle" that meant causing a fungicide insoluble in water to be carried into wood with the aid of a solvent which was completely miscible with water. His suggestion was PCP dissolved in diacetone alcohol with perhaps an antiblooming agent added.

The other speaker on the PCP subject was Dr. W Scholles from Desowag-Chemie, Düsseldorf. He recommended a product called SOWASIL-BS which consisted of sodium pentachlorophenate and borates. To this formula was added an adjusted portion of sodium carbonate to give the aqueous solution a light alkalinity.

The subject of fluorine compounds had been assigned to Bror Häger, M.Sc.. His suggestion was a mixture of alkali salts of hydrofluoric acid, chlorophenols and benzoic acid in equal parts. He presented a scenario in which the wood to start with was to be treated with a 10%

solution of the salt mixture. After a while, the concentration of the salt mixture with growth-preventing substances was to be diminished and instead substances for the purpose of dimensional stabilization were to be added to the solution in a continuous process.

The arsenic formula was presented by Lars Birkner M.Sc., Boliden Mining Company (Boliden Gruv AB). The company had developed a product called Bolit B. This contained borates besides arsenic and chromium salts. The product´s high solubility and penetrability into wood was stressed by Birkner.

Dimension-stabilizing Substances

Compatibility with polyethylene glycol was stressed whenever a fungicidal formula was presented. On 7 September 1961, Rolf Morén, Mo & Domsjö AB, gave a presentation to the Conservation Council called “Dimensional stabilization of wood with polyethylene glycol” (18). The presentation was received with great interest by the council members. In order to obtain a complete picture of the functioning of PEG, the chairman of the Conservation Council, Bertil Thunell, put eight questions concerning the substance.

He first pointed out that the results hitherto obtained had been from disconnected material. Were the results applicable to the hull? To this, Morén answered that he thought it suitable that tests were made with PEG’s of lower molecular weight such as e.g. PEG 400 or 600.
The second question was about methods to check the penetration of PEG. This was somewhat complicated and had to be analysed from core samples. The third question dealt with the desirability of penetration into the heartwood that had not been achieved in the test preservation referred to by Morén. On that issue, the Conservation Council and Morén differed in their opinion, in that the council stressed that there should be a penetration into the heartwood and also that it was possible for PEG to achieve this. Morén had shown that cracks could be made to close by swelling the wood in a PEG solution. To the fourth question that concerned this property, Morén answered that this had only been done to newly developed cracks and he did not know about older cracks that had stabilized over a period of some length. To the fifth to eighth questions, Morén gave his opinion that the stabilizing effect of PEG was of a mechanical nature, that the pH value was not important for the penetration although he preferred a high pH value, that there was no "after-sweating" due to depolymerization of PEG and that PEG-treated wood could be surface treated with polyurethane or epoxy lacquer.

To obtain some information about the treatment of waterlogged wood with carboxy-methylcellulose (CMC), an invitation had been issued to Gerrit van der Heide, director of the Wieringermeer, Shokland, the Netherlands, who had been contacted by Clason in September 1960 on the subject of wood preservation. He reported in a reply to Clason dated 24 June 1961 on CMC as a dimension-stabilizing agent, and he also referred to PEG (33). In his letter, he said that the "methylcellulose as well as polyethylene glycol must penetrate to the centre of the wood in question". He referred to ten years of experience with methylcellulose and said in his letter that "the methylcellulose gives the best results so far". He mentioned that he had only just started work with PEG, but he gave his opinion that the main problem is keeping the wood as wet as possible which is of vital importance for the penetration of the stabilizing agent, whether this is CMC or PEG 4000. In answer to the invitation, he sent a letter and a sample of CMC for testing purposes. Although van der Heide had no opportunity to attend a meeting, CMC was considered together with PEG when the choice of biocide was discussed.

Testing the Biocidal Products

Test Treatments

At the seventh meeting of the Conservation Council, Barkman gave an account of the test treatments and evaluations of those treatments which were planned to take place in order to perform a mycological, chemical and physical investigation of the effects of the suggested biocides. Three series were to be set up. The purpose of the first was to check the amount of drying and cracking of untreated timber in 95% relative humidity and room temperature. For the second series, a large waterlogged beam from a nearly contemporary wooden warship was to be cut up and used to test the formulae from Desowag, Dr. Winbladh, Häger, Birkner and perhaps some compositions made at the Vasa conservation laboratory. The treatment was to be repeated with testmaterial from the Vasa, which was the third series.

Five test pieces, each 25 centimetres long from a beam that had a transverse section of 30 x 45 centimetres, were treated according to instructions given by the four manufacturers. Two were treated with PCP in different organic solvents, the third with Bolit B and the fourth with Sowasil BS. The last test piece was treated with a special formula that was put together for the purpose by Häger. This composition contained 7% of biocide. Part of it was sodium pentachlorophenate (35). After the treatment with biocides, one half of each of the treated surfaces of the first-mentioned test pieces were painted with a 30% by weight solution of PEG 4000. These treatments were performed during the first half of September 1961.

For the tests using Vasa material, seven specimens were prepared (34). One of these was kept untreated to serve as a reference. The same biocide treatments as the first four mentioned in the series above were applied to four of the specimens, while the two remaining specimens were treated with formulae made by the conservation laboratory. One was 10% by weight of each of the two substances PCP and its sodium salt dissolved in ethyl alcohol. The other was 2% by weight of phenol and 30% by weight of PEG 4000 in aqueous solution. Those treatments were applied at the beginning of November 1961. Because Häger had collected his sample in October, his formula was not considered for inclusion in the third test series.

Testing at the Royal College of Forestry

The Conservation Council member Björkman had offered the services of the Royal College of Forestry for testing the different biocides under equal circumstances. He judged mould and rotting fungi to be the main problem, so he decided to use one species of mould fungus and two species of rotting fungi that specialised in oak. At the beginning of December 1961, six cores taken from each of the test pieces treated with PCP in organic solvents, Sowasil BS and Bolit B were sent to the Royal College of Forestry to be tested. Since Häger had collected his sample in October, it could not be included in the test. Later in December, four cores taken with a drill from each of the treated and untreated specimens of the third test series were also sent to the Royal College of Forestry. In the middle of January 1962, a further eight cores from each of the specimens were added to the mycological test series.

The testing was performed over a period of time and, in February 1962, at the twelfth meeting of the Conservation Council, Björkman gave a preliminary report of the results. At that time, Bolit B and 10% each of PCP and sodium PCP gave the best results. However, when the Bolit-B-treated test piece was tested at a high relative humidity, it was found to be hygroscopic and for this reason it was discarded from the list of possible biocides. Since the mixture of PCP and sodium PCP had to be dissolved in an organic solvent, this was not considered either (84).

To monitor the effect of the treatment, samples were taken from the outside planking of the Vasa hull. The samples were inoculated for a period of five months with pure cultivations of *Lenzites quercina* and *Polyporus sulphureus*. Both of those were chosen for their high capacity to degrade oak wood.

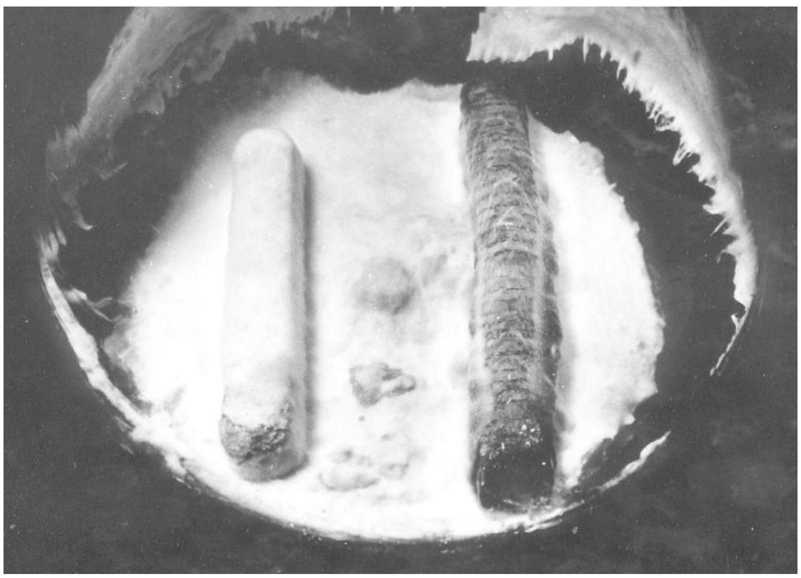

Figure 4-1 Attack by *Lenzites quercina* on untreated recent oak to the left and untreated Vasa oak to the right (photo: The Royal College of Forestry)

Preliminary tests, had shown however, that the Vasa oak had a higher resistance than recent oak wood to attack by these fungi. Inoculation with the two species of oak-rotting fungi led to weight losses of only 8.4 and 7.8% respectively on untreated Vasa oak, whereas the recent oak samples that were inoculated at the same time showed weight losses of respectively 21.0 and 23.2% (figure 4-1).

The test series that was finished in May 1966 showed no visible attack on the treated Vasa oak and the weight losses recorded were 2.2 and 3.8% respectively (figure 4-2) (41).
oak and the weight losses recorded were 2.2 and 3.8% respectively (figure 4-2) (41).

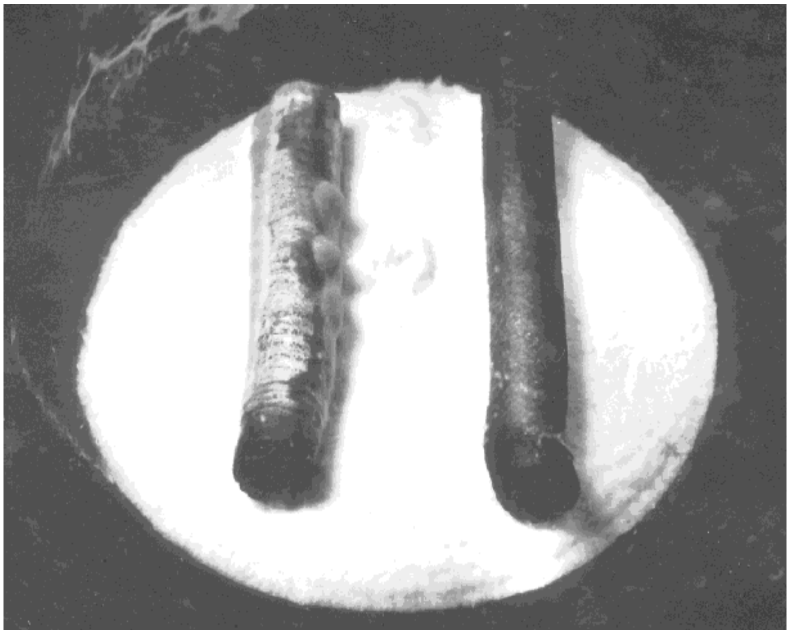

Figure 4-2 Attack by *Lenzites quercina* on samples of untreated Vasa oak to the left and treated Vasa oak to the right (photo: The Royal College of Forestry)

Judging between Polyethylene Glycol and CMC

There was some knowledge about the first of the two competing dimension-stabilizing substances, PEG 4000 and CMC, because it had been used for the disconnected Vasa finds and had also been tested together with the biocides in the second test series. Some tests had been made with CMC, but there was no obvious advantage in using that substance (36).

The Decision

In January 1962 when the Vasa hull had come into shelter in the pontoon superstructure, Barkman reported to the Board of the Vasa that the preservation treatment was to start after 16 February. At that time, the technical equipment of the pontoon superstructure would be completed. The programme he put forward was treatment with a "strong" formula for three to four months. Thereafter a "milder" formula was to be applied and then the polyglycol treatment would start.

Choice of Solvent

The possibility of using an organic solvent as a vehicle for carrying the preservation substances into the wood structure was discussed, and some experimental work was done with diacetone alcohol mixtures with water as solvent for sodium pentachlorophenate by the Vasa conservation research and analysis laboratory in accordance with a suggestion made by Dr Winblad, BP.

Among the suggestions for a preservation system that were put forward by experts working in the preservation field, Bror Häger, M.Sc., presented a formula based on the principle of making a water-in-oil emulsion take up water and leave fungicide and dimension-stabilizing substances in the wood. The formula was tested as a preservation agent by the research laboratory.

Because of the fire hazards involved in the handling of organic solvents and resins, it was decided to choose water as the sole solvent. This called for the use of only water-soluble dimension-stabilizing and fungal and bacterial growth-controlling substances.

Hypothesis of the Mechanism of Dimension Stabilization with Polyethylene Glycol

The wood experts were of the opinion that the dimension-stabilizing effect of polyethylene glycol on wood was due to the substance penetrating the cell wall and replacing water on the hydrogen bonds in the matrix of the secondary cell wall.

Choice of Preservation Method

Hypothesis of the Preservation Process

The hypothesis of the preservation process was that the water-soluble preservative should enter the wood by diffusion of the molecules of preservative from an aqueous solution into the water of the wood structure.

The obvious way to achieve this was to bring an aqueous solution of gradually increasing preservative concentration into contact with the surfaces of the waterlogged wooden object for as long a period as it takes for the water or the aqueous solution of preservative in the wood structure to reach the same concentration of preservative as the treatment solution. The process was supposed to be able to exchange the whole amount of water in the wood for preservative or it could be stopped when a prechosen level of preservative in the wood had been reached.

To assure continuous access of the preservation liquid to all the surfaces of the wooden object, tank treatment would have been necessary. For the Vasa hull, as a very large wooden object, an application by spraying was necessary for practical reasons.

The Test Panels

Because spray treatment with PEG on a large scale had never been performed before, it was decided on the recommendation of the Conservation Council (82) to carry out a rather large-scale test before the treatment of the Vasa was started. It had been made clear to everyone responsible for the Vasa that fresh wood did not have the same characteristics as wood from a ship that had spent more than three hundred years on the bottom of the sea. To perform a proper test, it was necessary to use wood with characteristics that resembled those of the Vasa wood. The parameters to be tested made it necessary to use identical material for a number of parallel treatments.

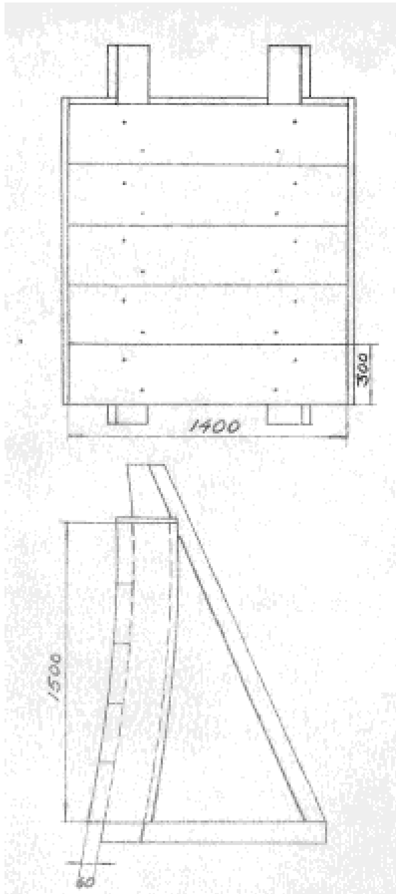

Figure 4-3 Contruction drawings of the test panels (Bo Lundvall 1963)

To obtain useful information it would be necessary to choose the parameters of the test situation so that some of the treatments might not be satisfactory. This made it impossible to take out material from the Vasa hull for the experiment. There were, however, other wrecks with known positions of about the same age and history as the Vasa. As there had been no idea that anyone would ever salvage these vessels, some timbers had already been taken and used for private purposes from another man of war whose foundering place was situated just outside the Stockholm harbour. The Board of the Vasa made an application to the Swedish Naval Forces who owns all foundered warships to salvage some constructional timbers from this already damaged ship. The application was granted and the diving operation took place in September 1961. The divers brought up some ribs and planking from the sunken warship.

With this oak wood material, it was possible to construct four panels 1.5 by 1.5 metres (figures 4-3 and 4-4). The panels were designed with a wall of fresh wood doubling the old material on the reverse side and leaving a space of about fifteen centimetres between the two walls. This space was closed at the top (figure 4-3). The construction was designed to prevent too rapid drying from the reverse sides of the old timbers.

Figure 4-4 The test panels before conservation treatment (photo: Gerhard Bauer)

PEG 4000 was tested by itself on one panel and in combination with PEG 1500 on the other two panels. The fourth panel was kept as reference.

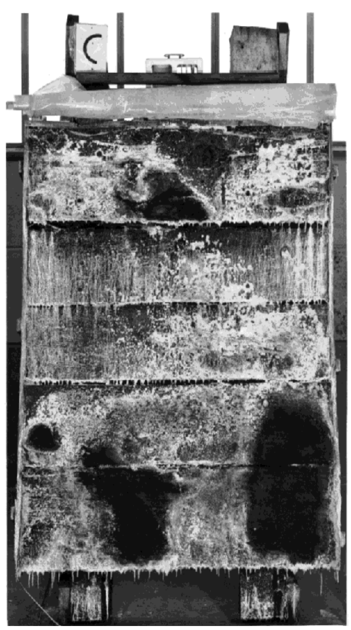

Figure 4-5 Test panel C after conservation treatment (photo: Gerhard Bauer)

The panels were protected by plastic sheets during the treatment period to slow down the rate of evaporation from the surfaces under treatment and thereby promote the diffusion process. The treatment was continued until there was a white precipitate of PEG on the surfaces of the panels (figure 4-5). It took about six months to reach this stage.

To come to an understanding about the reaction to different rates of drying, the plastic sheet protection was removed from one of the pair of equally treated panels immediately after the treatment had been finished. The whole process of treatment and drying was carried out at 20°C. The relative humidity during the drying process without protection varied between 35 and 90 %.

To monitor the preservation and drying procedures, core samples were taken and analysed. Strain gauge measuring units were mounted on the panels to monitor dimensional changes (figure 4-6).

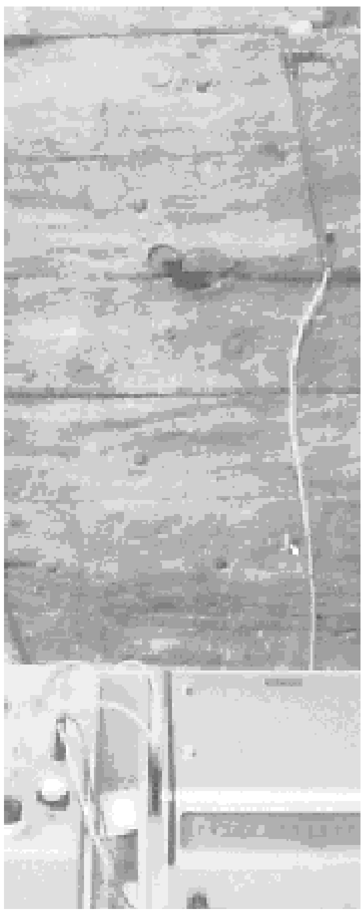

Figure 4-6 Measuring dimensional changes in the wood with a strain gauge (photo: Stefan Evensen)

From the test treatment, the conclusion was drawn that the diffusion of PEG was very slow and had to be promoted by maintaining a high water content in the wood. This should be done by maintaining a high relative humidity in the surrounding air during the diffusion period.

Preservation Performance - The Hand Spray System

A system for spray treatment of the Vasa hull was constructed as one of the installations in the pontoon superstructure. Putting it into action became the task of Knut Svensson, who was works manager at the conservation department.

The preservation system consisted of a tank with a volume of three cubic metres that was placed onshore in a special building. From the tank, the preservation solution was fed by means of a pneumatic pump into one system of pipelines outside and another inside the Vasa hull (2, p 16). Both systems consisted of a set of two parallel pipelines, one for compressed air and the other for the preservation solution. The pipeline pair was installed on three levels on the outside of the hull and on three levels inside the hull. The pipeline for distribution of preservative solution on the outside of the hull had a diameter of 50 mm while the corresponding pipeline on the inside had a diameter of 40 mm. The pipeline system for compressed air had a diameter of 25 mm. Each of the systems for preservative solution and compressed air was equipped with 72 snap connections for connecting hand sprays on the outside and 48 inside the hull.

The sprays that were used in the system had one connection for feeding preservative solution into the spray and one connection for feeding compressed air for the jet. The construction prevents air from mixing with the preservative solution.

The equipment for dissolving the preservatives consisted of two oil-jacketed tanks, each with a volume of six cubic metres. The tanks could be heated to the boiling point of water. They were placed in the same building as the tank for the preservative solution.

In the same building, there were also two compressors, one of which was used to keep the pneumatic pump going and to feed the compressed air system for the spray function. A valve construction on the preservation liquid tank could change to compressed air in order to flush the preservation liquid system after a round of treatment had been completed.

The other compressor was used to operate the air humidifying system.

Fungicide Treatment

During the period in the open air when the outside of the hull had been sprayed with sea water, green algae had appeared on the outside surfaces. A remedy was needed and an aqueous solution of sodium pentachlorophenate (NaPCP) was chosen because of its effectiveness on surface growths. This substance did not however penetrate very deep into the Vasa wood, as it precipitated because of the acidity of the oakwood. One way of enhancing the solubility of NaPCP in water was to add some polyethylene glycol to the solution as an "antiblooming" substance, as had been patented by MoDo through Rolf Morén.

During the period from the beginning of April 1962 until the end of 1963, one round per month of NaPCP solution was sprayed on to the hull. To enhance the solubility of the NaPCP, the hull was sprayed daily at first with a 20% PEG 800 and then with a 25% PEG 1500 solution in water. From the end of May 1962, the PEG concentration of the spraying liquid was reduced to 12.5% and one per cent of the borate formula TIMBOR was added. At the end of June 1962, the PEG 1500 was exchanged for PEG 4000.

During the period until the end of 1963, when the treatment with NaPCP was finished, 468 tons of preservation liquid had been sprayed onto the Vasa hull. For the whole period of time, the preservation liquid had contained polyethylene glycol and for most of the period also a borate formula. The consumptions of PEG and borates were 68 and 24 tons respectively. For the spraying once a month with NaPCP, four hundred and eighty kilograms of that substance were used.

The Preservation Solution

It had been suggested that, in addition to the commercial fungicides and chemical substances tested as fungicides, the Vasa conservation laboratory should compose a formula of its own. This should be based on borates that at that time were being tested on a large scale by the wood preservation industry. The one obvious disadvantage of borates, i.e. their high solubility, would not disturb their use for the Vasa ship that was going to be kept indoors in a controlled climate.

The formula composed by the conservation laboratory was a combination of PEG and a boric acid - borate system. The PEG´s used were labelled 4000 and 1540 with molecular weight ranges of 3000 - 3700 and 1300 - 1600 and melting ranges of 53.0 to 56.0 and 43.0 to 46.0°C respectively (19). The boric acid and borate (borax) were analytical grade chemicals.

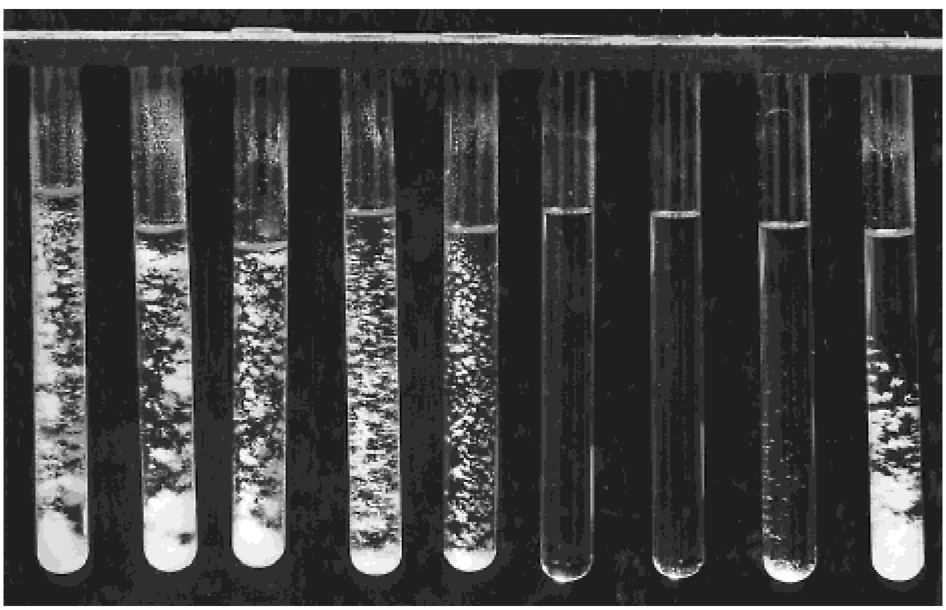

Figure 4-7 7%w/w of boric acid - borax mixtures 1:9, 2:8, ….9:1 in 30% PEG 4000 solution in water (photo: Gerhard Bauer)

According to tests made at the Vasa conservation laboratory, boric acid and borax dissolve to an extent of only five and four per cent respectively in water at room temperature. However, the two substances mutually enhance their solubilities in water so that a 1:1 mixture dissolves to an extent of more than 23 per cent, which was the highest concentration tested by the Vasa conservation laboratory.

To obtain some idea of the effect of PEG on the equilibrium ratio between boric acid and borax, nine mixtures of the two substances in weight ratios 9:1, 8:2......to 1:9 were prepared. Eleven series of 1, 2 ... etc % w/w of each of those mixtures and the pure substances were dissolved in distilled water and in 10, 20, 30, 40 and 50% solutions of PEG 4000 and 1500. The state of precipitation was investigated after a period of two weeks (figure 4-7). The pH values of the samples that were still in a dissolved state after the two-week period were determined and tabulated for all concentrations of each of the PEG´s.

The overall picture is that the solubility of the boric acid - borax mixtures decreases with increasing PEG concentration. The highest concentration of the salt mixture in any proportion drops from 23% in pure water to 8% in a 50% solution of either PEG. With increasing PEG concentration there is also a shift in the proportions of the boric acid - borax mixture that shows the highest solubility from 5:5 in pure water to 8:2 in 50% PEG solution. This shift is slightly faster with PEG 4000 than with PEG 1500 but at 50% the two PEG´s end up with the same salt mixtures. In all the PEG solutions, the pure boric acid dissolves to 4% whereas the borax does not dissolve at all in the PEG solutions with a concentration higher than 30%.

The pH-values of the solutions tend to be neutral or on the alkaline side. The pH-values decrease with increasing concentration of the boric acid - borax mixture. In contrast, the pH-value increases for a given salt ratio of a given concentration with increasing PEG concentration (figure 4-8).

PEG %	PEG 1500	PEG 4000
10	7.28	7.52
20	7.47	7.83
30	7.47	7.72
40	7.52	8.07
50	7.93	8.63

FIgure 4-8 pH values of 3% of boric acid - borax mixture 8:2 in PEG solutions

Although the 8:2 mixture was the only one that showed a steady solubility through all the concentrations of PEG, the 7:3 mixture was chosen for the conservation of the Vasa. This was because of its higher buffering capacity on the acid side which was judged to be of benefit if another round of treatment with NaPCP had to be performed.

Preservation Treatment

From 5 July 1962, the conservation liquid that had been developed by the research unit of the conservation laboratory was put into use with a composition of 15% PEG 4000 and 6% boric acid - borax mixture in the proportions 7:3. This composition was kept unchanged for use on the surfaces of the Vasa hull that lay open to the eye. However, to achieve sufficient preservation of the ribs, a composition with the same concentrations of PEG and the borate formula was used, the only distinction being that it was prepared with PEG 1500 instead of 4000.

The preservation treatment was carried out by hand by two teams, each consisting of five labourers using preservation solution from the pipeline system. One complete round of spray treatment took five hours. This limited the number of rounds that it was possible to carry out per 24 hour period. At first, spraying was performed only on weekdays, but from May until December 1963 also on Saturdays and Sundays. During the winter months, there was a six-days-a-week programme and spraying into the space between the outer and inner plankings was also started.

Even during 1964 there was one additional round of spraying with NaPCP, making the total amount of that substance consumed equal to five hundred and twenty kilograms. In all, the spraying had consumed a total of nearly 900 tons of liquid containing 130 tons of PEG and fifty tons of borate formula during the hand spraying period from April 1962 until the start-up of the automatic system in March 1965.

The Automatic Spray System

The question of an automatic spray system was first raised by Schoerner at a meeting of the Conservation Council on 6 September 1962, but none of the other council members supported the suggestion at that time. At the Conservation Council meeting on 14 September 1964, the question was again raised by Barkman who suggested a permanent spray system that could be working day and night. The aim was to diminish costs and time for the preservation of the hull. This time, the members of the council agreed to the idea and recommended that plans and cost calculations for the project be made as soon as possible.

A preliminary design was made by the design office of the Vasa museum. The preservation plant was to have a tank for the preservation liquid and a pipeline system to which sprays would be connected (figure 4-9). The construction of the plant was finished in February 1965 and the plant was put into operation on 5 March of the same year.

The Tank

One of the compartments in the pontoon was used as a tank for the preservation liquid (figure 4-10). This compartment measured 5 x 5 x 3.3 metres. The walls of the compartment were painted with epoxy paint so that no substances should dissolve from the concrete into the liquid as a protection for both the pontoon and the liquid. Compressed air was used to stir the preservation solution in the tank and, for that purpose, a pressure rubber tubing was mounted with its lower end almost reaching to the bottom of the tank. Two pumps connected separately by lengths of rubber hose pipe, with filters on their suction ends to remove particles from the solution, pumped the liquid through the system (figure 4-10). During the spraying activity, a surplus of liquid was applied that eventually returned to the pontoon top plane. Thence it was drained by two outlets that were connected, each to a separate inlet in the tank, by a sewer pipeline.

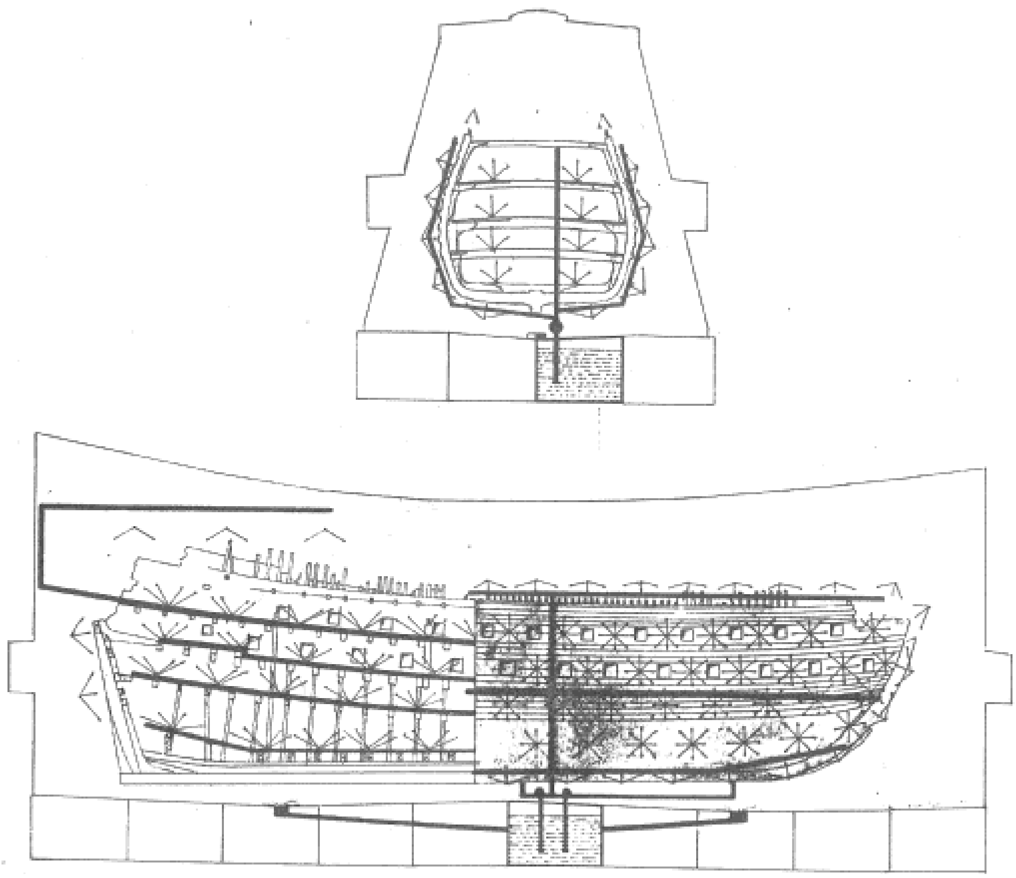

Figure 4-9 Diagram showing the preservation tank, the pipeline system and the locations of the sprays (drawing: Eva Maria Stolth)

The Distribution System

Above the tank, the pumps were connected to three vertically placed pipelines distributing the preservation liquid to the tops of each of the outer longsides and the inside of the hull. Connected to the vertical pipelines, horizontal pipelines were fitted at three levels on the outer longsides and on each of the decks inside the hull. The pipeline on the upper gundeck was later in 1965 extended so as to provide for the higher stern parts of the hull (figure 4-9).

On the horizontal pipelines, lengths of rubber pressure tubing with spray nozzles were mounted on special connectors. Inside the hull, the sprays were mounted on swinging spray sprinklers in order to be able to cover constructions both at the sides and above the spray.

Figure 4-10 The preservation tank with rubber hose pipes for pumping the solution and pressure tubing for stirring. A sewer pipeline on the wall of the tank is for returning liquid (photo: Göran Sallstedt)

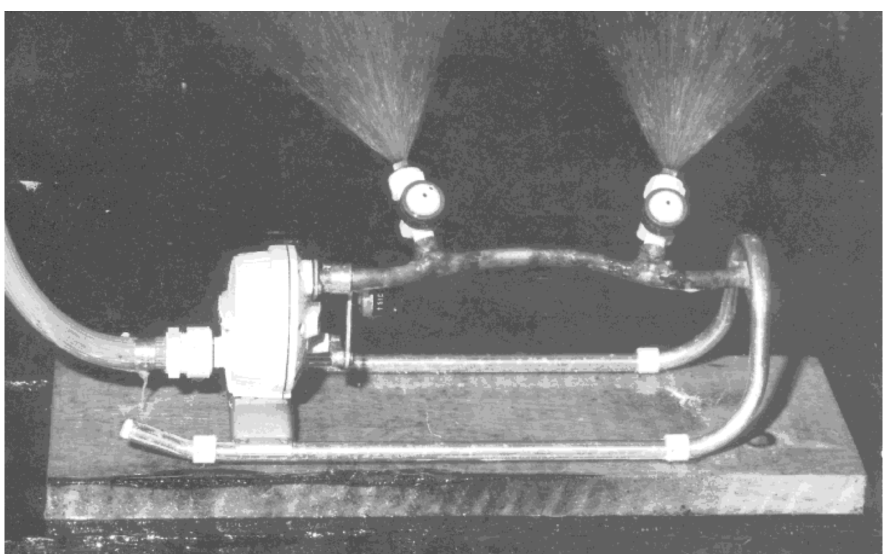

Figure 4-11 Swinging spray sprinkler with two nozzles (photo: Göran Sallstedt)

The sprays had different angles of delivery and different capacities depending on the part of the hull where they were designed to work. The sprays mounted on the swinging spray sprinklers had the smaller angle of delivery, 65 degrees and the higher capacity, 5.9 litres per minute at 3 kp/cm^2 pressure (figure 4-11), while those used on the outside of the hull had an angle of delivery of 120 degrees and a capacity of 3.1 litres per minute (figures 4-12 and 4-13).

Figure 4-12 Area of delivery of outside spray (photo: Göran Sallstedt)

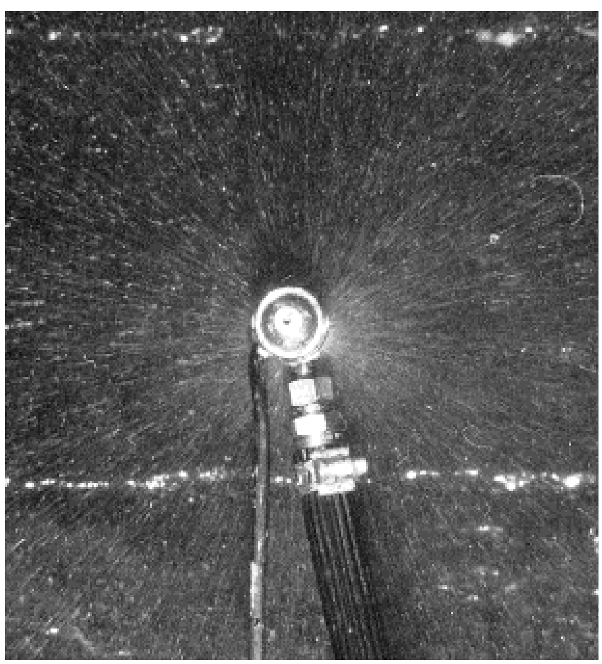

Figure 4-13 Area of delivery of outside spray (photo: Göran Sallstedt)

Sprays with the same capacity but with a flat delivery at an angle of 130 degrees were mounted to work from above between the outside and the inside plankings so that the preservation liquid should reach into the space of the ribs and into every possible gap between the timbers of the constructional unit of the ship´s sides (figure 4-14).

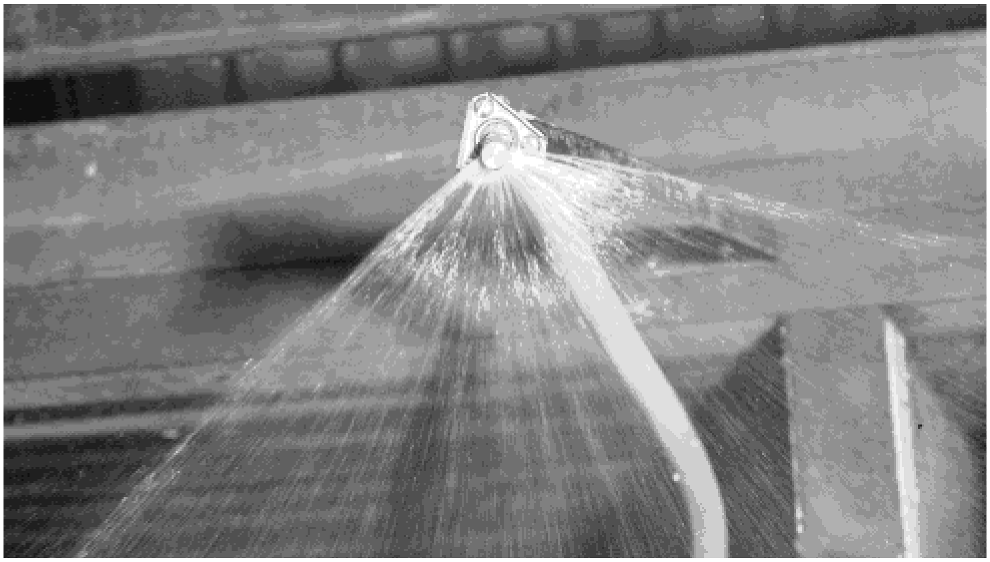

Figure 4-14 Delivery from spray nozzle into the space between the outside and the inside plankings (photo: Göran Sallstedt)

In all, the construction consisted of about 600 metres of pipeline, 800 metres of pressure rubber tubing, about 100 swinging spray sprinklers, each with two sprays and about 200 fixed mounted sprays (figure 4-15).

Quantity	Description
600 m	Quick coupling pipes, 2" and 3"
800 m	Rubber pressure hoses, ½"
96	Swinging spray sprinklers, type Melnor, modified for
96 x 2	Nylon diaphragm nozzles, type 8360-6515, flat spray, 5.9 1/min each at 3 kp/cm^2, spray angle 65°
175	Fulljet nozzles, type 1/8 GG 4.3 W, wide angle full cone, 3.1 1/min at 3 kp/cm^2, spray angle 120°. Each nozzle mounted on a diaphragm check valve, type 4666, for drip free shut-off
22	Floodjet nozzles, type 1/8 K 5, wide flat spray, 3.1 1/min at 3 kp/cm^2, spray angle 130°
150	Pipe connectors, type 8370 A - 1½ x ½ Split-Eyelet Connector, with T-type hose nipple
4	Line strainers, type 2 ½ TW - 80 x 70 mesh, open area 4 times pipe area
2	Loewe Centrifugal pumps, 25 hk, 800 1/min

Figure 4-15 Data of the Automatic Preservation Plant

The Operating System

The pipeline system was split into four parts at the start. Later this was changed to five parts. Each part was separated from the rest of the system by a magnetically operated valve. Each valve was put into operation by a time-switch-operated relay so that each part of the spray system could be in operation at pre-set hours for a pre-set period of time. The pumps were also started and switched off by the relay system.

Handling the Automatic Spray System

The functioning of the automatic spray system was checked daily and the system was equipped with an alarm signal to the board in the nightwatchman's box. If a disturbance was noticed, the nightwatchman called in one of the engineers in charge of the system or a maintenance man.

During the spraying activity, particles in the solution that were too small to get caught in the filter nets impaired the performance of the sprays so that they had to be cleaned out. This was done by hand and it had to be done when the spray was working so that its functioning could be checked.

Two engineers and two untrained labourers were on the museum staff to take care of the handling of the automatic spray system. The working hours spent on this task corresponded to 50 per cent of an engineer´s and 100 per cent of a labourer´s employment.

The Preservation Solution

Volume of Preservation Solution in the Tank

The volume of preservation liquid in the tank was 10 cubic metres at the start. Later, when two pumps were needed to feed the enlarged spray system, the volume was brought up to 20 cubic metres. When the spraying frequency was decreased, so that one pump was enough, the volume of preservation liquid was brought down to the original 10 cubic metres.

Spray Period and Frequency

The spray period was generally five minutes for each relay-operated part of the pipeline system. Since the outside planking was the victim of a higher ventilation capacity, it was for most of the time treated for ten minutes in each spraying round.

During the ten-year period from March 1965 to March 1975, the purpose of the treatment was to augment the PEG uptake of the Vasa wood. The period consists of a seven and a half year period of intensive spraying during which all the surfaces were treated 32 times per 24 hour period. Thereafter there was a period of about two and a half years of successively less frequent spraying ending at six times per 24 hour period with the purpose of raising the polyethylene glycol content in the deeper layers of the wood as a transition to the final stages of the treatment period (figure 4-16).

period					spraying rounds/ 24 hour period
Apr.	65	-	Oct.	72	32
Nov.	72	-	Feb.	73	21
Mar.	73	-	Aug.	73	19
Sept.	73	-	Dec.	73	16
Jan.	74	-	Aug.	74	9
Sept.	74	-	Dec.	74	6
Jan.	75	-	Jan.	75	3
Feb.	75	-	Mar.	75	6
Apr.	75	-	Sept.	75	4
Oct.	75	-	Feb.	77	2
Mar.	77	-	Jan.	79	1

Figure 4-16 Preservation of the Vasa hull; Number of spraying rounds per 24 hour period

At the beginning of 1975, the museum director, after consulting the Conservation Council, decided that the final stage of the treatment that aimed at drying the Vasa should start. This was confirmed by Barkman in a memorandum of 20 March 1975 (46) to the museum director, in which the programme for the final part of the spray period was scheduled. The spray treatment was to take place only at night. The purpose of the spray treatment was to provide a surface protection and to control the drying process. The number of sprayings per night was set to four for the summer period of 1975. From 1 October 1975, the number was reduced to only two per night for a period of one and a half years. From March 1977, the number of sprayings was cut down to one per night. To improve the spraying picture, the length of each spraying period was doubled to 10 minutes from January 1978 until January 1979 when the treatment was stopped.

Solution Consumed

During the intensive spray treatment period there was no extra humidification of the air in the pontoon superstructure, but the recorded relative humidity was a result of evaporation from the preservation liquid. During the less intensive part and the final part of the treatment period, a humidification system was put into function to maintain the desired relative humidity in the building.

To calculate the amount of polyethlene glycol solution that was consumed, the initial amount plus all added portions less the residual amount after the treatment was finished, must be identified. The total amount of preservation liquid that has been handled in the preservation tank amounts to 3600 tonnes.

Choice of Molecular Weight of Polyethylene Glycol (PEG)

At the meeting of the Conservation Council on 14 September 1964, it was suggested that the possibility of using PEG 1500 instead of PEG 4000 for the preservation of the hull should be investigated. The reason was that a liquid of lower viscosity than the PEG 4000 solution was desired to achieve a satisfying spraying picture with a reasonable number of sprays.

PEG 4000 was still considered to be the PEG best suited for museum objects. The properties specially appreciated were its low hygroscopicity and the rather high melting point of about 56° C. The hygroscopicity curve of PEG 1500 closely resembles that of PEG 4000, while its melting point lies about 10° C below the melting point of PEG 4000. The differences were considered to be acceptable and PEG 1500 was chosen for the automatic spray system on the grounds of the lower viscosity of its solutions in water compared to that of PEG 4000.

Because of the change to PEG 1500, the research and analysis laboratory started research on how the differences between PEG 1500 and PEG 4000 would effect the preservation process and the conservation result. To obtain a broader perspective, PEG 600 and PEG 1000 were included in the research programme. One result was that it was found that the lower molecular weight PEG´s had a greater dimension-stabilizing effect. Their higher hygroscopicities and low melting points proved by practical investigation to cause no trouble when keeping the preserved Vasa wood in the planned museum climate. It was therefore decided early in 1971 to start using PEG 600 in the preservation tank.

This decision was effectuated with start on 5 March 1971 by using PEG 600 to restore and later to raise the PEG concentration in the tank. The original PEG 1500 solution was not however discarded, so a preservation solution with an increasing proportion of PEG 600 and a decreasing proportion of PEG 1500 was created.

Concentration of PEG in the Preservation Tank

Preservation Schedule

The preservation was designed to be performed by starting with a low PEG concentration in the preservation solution and ending with a rather high one. A PEG concentration of 10% was chosen for the start of the preservation process (figure 4-16). The final concentration was not decided upon at the start. However, a solution with a PEG concentration higher than 45% gave a less satisfactory spraying picture. This established 45% as end concentration. The main principle when deciding to raise the PEG concentration of the solution was that an equilibrium had been established between the PEG concentration in the solution and the PEG in the wood.

Performance according to the Equilibrium Concept

The PEG contents of the wood were determined by analysing core samples. Each sample had to contain a rather high number of cores to be considered to give reliable information about the level of PEG in the wood. The PEG-ratio values in the wood were however rather scattered, so it was not easy to determine whether or not equilibrium had been reached. With no guiding precursor, great caution was applied and the first 5% increment in the solution concentration was not made until March 1967. The 15% level thus reached was, for the same reason, kept for a period of three years (figure 4-17).

At the meeting of the Conservation Council on 30 October 1969, Barkman suggested that the PEG concentration in the solution should be raised to 20%. The council members did not support the suggestion. Instead, the possible reasons for the fact that no appreciable increase in PEG content in the wood was shown from the analyses of the two core samples taken in December 1966 and May 1968 were discussed. The amount of PEG added to the tank should have led to an increase by 3 percentage points of the PEG content in the wood. The question was raised as to the possibility of a hindrance in the wood to the penetration of PEG. Another matter of interest was where the PEG added to the tank during that period of time was. A group consisting of Barkman, Thunell and Rånby was charged with the task of investigating the situation.

Because the pontoon superstructure was to be enlarged during the autumn of 1968, in order to be able to house the fore and stern parts of the Vasa that was growing during reconstruction work, the air in the pontoon superstructure had been sampled in order to establish the conditions in the original housing. The loose surface layer of the pontoon concrete roof that was the floor on which the Vasa was standing had also been scraped off and analysed for PEG. The construction work on the pontoon superstructure also made it possible to take core samples from the concrete roof of the pontoon that showed the situation down to a depth of nearly 10 cm. The Conservation Council considered the material presented at a meeting on 9 October 1968 and drew the conclusion from the data relating to PEG contents in the air and in the concrete of the pontoon that neither could account for a loss of PEG of the discussed order of magnitude.

Despite the absence of a recommendation from the Conservation Council, the PEG concentration in the preservation solution was raised to 20% in January 1970 (figure 4-17).

The group that was investigating the suspected loss of PEG had also been given the task of looking into the question of a schedule for raising the PEG concentration of the preservation solution. The results of their deliberations were reported by Barkman at the meeting of the Conservation Council on 12 June 1970. The recommendations were that the concentration should be raised from 20 to 25% with no delay and that another increment of 10% should be planned for the autumn of 1971. The reaction to this was that the PEG concentration was raised to 25%, at which level it was kept for one and a half years from July 1970 until the end of 1972 (figure 4-17).

period					PEG-conc %
Mar.	65	-	Feb.	67	10
Mar.	67	-	Jan.	70	15
Feb.	70	-	June	70	20
Jul.	70	-	Dec.	72	25
Jan.	73	-	Sept.	73	30
Oct.	73	-	Aug.	74	35
Sept.	74	-	Jan.	79	45

Figure 4-17 Preservation of the Wasa hull; Concentration of spray solution

At the meeting on 20 August 1970, the Conservation Council made a note to the fact that the increase to 25% PEG in the preservation solution in the tank had been followed by an augmented rate of PEG consumption that had about trebled during the first month. To obtain information about the effect on the PEG-ratio in the wood, the concil recommended that a sample consisting of fourteen cores, half from the outer and the other half from the inner planking, be taken.

The high PEG consumption also gave a new impulse to look for possible sources of PEG loss. The poor quality of the pontoon superstructure´s insulating capacity gave rise to the suspicion that either the rockwool insulation had left its fastenings and become dislocated or that its insulating capacity might have been impaired by PEG droplets penetrating into the walls with the aid of air leakage. To follow up the possible PEG loss, it was decided that a statistically reliable number of samples were to be taken from the insulation during an investigation into the walls of the pontoon superstructure.

The Conservation Council member Abramson suspected the analytical methods used and, in a memorandum dated 14 December 1972, he compared the average weights per unit length of some of the core samples after extraction with water for the analysis of PEG. From these data he drew the conclusion that a certain amount of PEG was trapped in the wood structure. The PEG that, according to Abramson, could not be extracted was calculated to be sufficient to account for the missing 12 - 13 percentage units of PEG. This would mean that there was no loss of PEG and that the amount of PEG in the wood was what could be expected from the PEG consumption figures. The Conservation Council adopted the proposed method of calculating the PEG contents in the wood from the core samples and used these PEG ratios as a basis for their recommendations about the execution of the preservation of the hull.

At the meeting on 20 December 1972, the Conservation Council recommended that the PEG concentration in the preservation solution should be raised to 30% and that another 5% increment should be planned after a six month period with the 30% solution. The concentration was raised to 30% in January and to 35% in October 1973 in accordance with this recommendation without further discussion (figure 4-17).

Accelerated Increase in Concentration

The yearly economic planning of the National Maritime Museum contained a schedule for the spray treatment of the hull that had been updated several times. At the Conservation Council meeting on 21 August 1974, Lundström raised the question of establishing the point in time when the spray treatment was to be finished. The reasons for raising this matter were partly economic and partly due to the fact that the plans for a permanent Vasa museum had been brought to life.

The idea that there was no loss of PEG led to the assumption that as long as PEG disappeared from the system there was an equal uptake of PEG into the wood. It was however noted that the consumption of PEG per unit time had been equally high since the increase to 35% PEG in the preservation solution (figure 4-18). This indicated that equilibrium between PEG in the solution and PEG in the wood had not yet been established.

Thus the question was to find a quicker way to reach the end-point of the conservation. To accomplish this, Rånby suggested that the PEG concentration should be raised, the spraying intensified and the preservation solution heated. The Conservation Council discussed the matter and agreed on a recommendation that the PEG concentration should be raised immediately to 50% and that the possibility of raising the temperature of the preservation solution should be investigated. No exact point in time for finishing the spray treatment was fixed.

period	PEG (kg.)	Borates as boric acid (kg.)
1965	17770	9150
1966	5220	1410
1967	14310	0
1968	22020	350
1969	14540	50
1970	31260	1100
1971	13720	430
1972	6220	40
1973	22500	1010
1974	31850	1200
1975	28920	60
1976	10425	5
1977	13265	60
1978	8970	0
1979	491	0
total	241481	14865

Figure 4-18 Consumption of PEG and Borates by the Automatic Spray System

At the next meeting of the Conservation Council, Barkman reported that the concentration had been raised to 43% and that this increase had caused the spraying picture to deteriorate. In his opinion, it was not advisable to raise the concentration further. The question of raising the temperature of the solution had been investigated by the consulting firm, BS-konsult, and a tender had been made for installing the necessary equipment. The Conservation Council recommended that the installation should be made. This was, however, never done. The PEG concentration in the preservation solution was kept at about 45% during the remaining period of four years and four months of spraying with the automatic spray system (figure 4-17).

End-point of the Treatment

The end-point of the spray treatment was discussed further. At the Conservation Council meeting on 13 November 1974, Abramson suggested that the treatment should be finished when the desired PEG-ratio had been reached in the wood. He also suggested that tank-treated Vasa oak material should set the standard. Comparing core samples from tank-treated material with those from the hull using his method of calculation, Abramson drew the conclusion that the hull had reached the same degree of conservation as the tank-treated material. On the basis of this information, the Conservation Council gave the opinion that it should be safe to end the spray treatment on trial from January 1975.

Discussions about the time when it would be suitable to stop the spray treatment were however still on the agenda at the meetings of the Conservation Council. Since the PEG concentration in the preservation solution had been raised to 45 %, Barkman had expressed apprehension that the drying of the timbers might be going too fast. This would prevent PEG from moving towards the inner parts of the wood and would also cause shrinkage and cracks. The conservation of the Vasa was the most important business of the Swedish National Maritime Museum. It was a task that stressed both the competence and the economy of the institution. The question of ending the spray period was therefore put on the agenda of the managing board of the museum at its first meeting in 1975 (75). The item was presented by the museum director and the chairman of the Conservation Council. After having heard the presentation, the managing board came to the decision that the spray treatment of the Vasa should be stopped on trial as soon as possible. The exact time for this was to be decided by the museum director. To be able to decide whether or not the spray treatment should be restarted, a group of people belonging to the museum staff with different specialities concerning the Vasa as a museum object and one external expert who was to be chosen by the museum director on the recommendation of the chairman of the board of specialists were charged with the task of monitoring the hull. The people chosen from the museum were three from the conservation staff and three from the restoration staff, including the heads of both departments. The monitoring was to be performed at least once every two weeks. On each occasion, the whole of the hull was to be scrutinized by visual inspection and measurements were to be made. The observations and measurements were to be recorded in a report that was to be delivered to the museum director and the chairman of the Conservation Council as soon as possible after each inspection.

The inspections were very meticulously performed and took a whole working day of eight hours on each occasion. Despite that, twelve inspections were made in 1975. The reports from these inspections were discussed at the meetings of both the Conservation Council and the managing board of the museum. At the meeting of the Conservation Council on 6 February 1976, three different programmes for ending the spray treatment of the Vasa hull were put forward. The first was proposed by Barkman, who wanted to raise the number of spray rounds per unit of time and to continue the spray treatment for a period of not longer than eight years. The second was proposed by Rånby, who wanted to continue spraying at the ongoing pace to the end of 1976 and after that at a lower pace until the end of 1977. The chairman, who was the author of the third programme, wanted to change to a lower pace immediately and stop the spray treatment at the end of 1976. The Conservation Council recommended proceeding according to the programme suggested by Rånby (107). This was confirmed as the decision of the museum by the managing board at their meeting on 22 April (76).

As Barkman did not agree that this would be the most suitable way of treating the Vasa hull, he appealed to the Swedish government to annul the decision that had been taken by the museum and to adopt the programme which he recommended for the treatment of the Vasa hull. The first step of the government was to refer the matter to the Swedish Maritime Museum management board for consideration. In their answer, the management board emphasized the competence of the Conservation Council and also the intensified programme for monitoring the condition of the hull. Because the difference of opinion remained, the government had to collect new information as a basis for its judgement. This was done by the Swedish National Council for Cultural Affairs, which asked for expert opinions from the National Museum of Denmark and from the Swedish Institute of Wood Research.

Both institutions attended to the task very seriously. The reply from the National Museum of Denmark was formulated by B Brorson Christensen who had been working with waterlogged material since long before the Vasa project started. He went through the projects he had been conducting and gave his opinion that no other substance than polyethylene glycol would have been suitable in the case of the Vasa. In answer to the question about the right time to stop the treatment, he made a comparison with the spray treatment of an oak vessel made at the National Museum. That vessel, which had oak planks that were 1.5 to 2 cm thick, had undergone spray treatment for eighteen months. Brorson Christensen did not venture to recalculate the time figure for a thicker material but concluded that "as long as the Vasa hull goes on taking up substantial amounts of the glycol (polyethylene glycol solution (author´s note)) that is sprayed onto it, it is my opinion that stopping the treatment will be a doubtful step, especially with simultaniously lowering of the moisture of the atmosphere" (47).

The scientist Solveig Johansson, who was charged with the task of preparing the report of the Swedish Institute of Wood Research, wanted to do some laboratory experiments of her own as a basis for her analysis. This would however have taken too long so instead she approached Håfors who was at that time in charge of the conservation research and chemical analysis of the Vasa project to get the necessary data. Johansson was invited to look into all the analysis and research material that was available. She chose to discuss the possibility that the analysis method for PEG might show too low a value of PEG-content of the preserved Vasa wood. She assumed that the real value might be about ten percentage units higher than the analysis value. However, she also pointed to the unevenness of distribution of the PEG in the wood. This led her to draw the conclusion in her report: "much indicates to that the spray treatment should be continued" (48).

The problem of stopping the spray treatment of the Vasa was also brought to the attention of the conservators´ organization. The organization had not been approached by the National Council for Cultural Affairs but was in a position to express its opinion. Maud Bennel, who was chairman of the organization, pointed out that it was difficult for people not involved to evaluate the status of preservation of the Vasa and to recommend how to proceed with the treatment. She stressed the successful treatment so far conducted by the head of the conservation department. The conservators´ organization therefore supported the programme put forward by the head of the conservation department (49).

The government replied to the management board of the Maritime Museum on 8 September 1977 (50). In its reply, the government drew the conclusion that there was no reason for the government to invalidate the decision made by the museum concerning the conservation of the Vasa. The reply also made a recommendation that the Swedish Institute for Wood Research should be consulted for advice and that the matter should be open for reconsideration whenever there was doubt about the conservation programme. Under the circumstances, Barkman felt that he could not take responsibility for the conservation management. He therefore resigned his position on 1 October 1978.

At the meeting on 13 December 1978, the specialists examined the data for PEG and water contents in the wood according to the 32nd sample that had been taken in August 1978. They found that no appreciable change in either had occurred since October 1977. The shrinkage measurements and a report from the monitoring group concerning the surveys made during 1978 were also considered. All the measurements and inspections indicated a rather stable situation.

It was however noted that the mean moisture ratio values were higher by thirteen percentage units in the inner planking than in the outer planking. The mean moisture ratio values of the heavy timbers of the hold and orlop deck were higher by twenty percentage units than the values of the heavy timbers of the upper and lower gundecks. On these grounds, the specialists gave their opinion that the most important task was to achieve a drying situation that would even out the noted differences in moisture content. Their recommendation was to look immediately into the possibilities of getting air with a lower moisture content than in the existing situation into the interior of the hull. They judged that the automatic spray system was no longer of any use and they recommended that it should be turned off. Rånby even expressed the opinion that the spray treatment in the existing situation rather delayed the desired evening out of the moisture content between differently situated timbers.

Håfors, who had moved from her position as research chemist to head of the conservation department when Barkman resigned, was in favour of changing the treatment programme more cautiously. She agreed with the specialists about accelerating drying of the interior of the hull by improving the ventilation. Because this would bring about a situation that would promote the absorption of the preservation solution by the wood inside the hull, she recommended that the spraying be continued (115).

Consumption of PEG

The automatic spray system was a continuous system, which means that no PEG was discarded from it. The yearly consumptions of PEG could thus easily be calculated. They have varied from about 5 to more than 30 tons. In all, 240 tons of PEG were consumed by the automatic spray system (figure 4-18).

Concentration of Boric Acid / Sodium Borate Mixture in the Preservation Solution

Concept of Concentration Management

Two factors have been decisive for managing the concentration of the boric acid / sodium borate mixture in the preservation solution. One was to ensure that a sufficiently large amount of borates was deposited in the wood of the Vasa hull and the other was the desire to maintain a pH value in the solution that would make it as harmless as possible with regard to decomposition of the wood substances.

The concentration of borates in the preservation solution was chosen to be 4% at the beginning of the process. During the first year of treatment, the aim was to maintain that level (figure 4-19) but, at the meeting of the Conservation Council on 3 May 1966, Barkman gave his opinion that the amount of borates in the wood was high enough and that the treatment with borates might be stopped. The grounds for this view were the fact that samples taken from the hull and tested by Björkman with various fungi known to be aggressive to oak had shown that the Vasa oak had gained a high resistivity to those fungi. A certain level of borates was however necessary in the preservation solution to keep the borates in the wood from dissolving back into the solution.

At the Conservation Council meeting on 4 May 1970, an analysis of the preservation solution made by Mo&Domsjö laboratories and dated 13 April 1970 was discussed. According to this, the preservation solution had a higher acidity calculated as acetic acid than a PEG reference solution. This might indicate oxidization and possible decomposition of the PEG molecule or that acid products had been dissolved from the wood of the hull. If the first mentioned situation applied, Rånby suggested that there might be a bacterial decomposition of PEG and that an increase in the borate concentration might be advisable. If, on the other hand, the latter situation applied, a chemical decomposition of wood substance might be taking place and adjustment of the pH value could be a way to diminish this.

The special group consisting of Barkman, Rånby and Thunell that was formed to work out a schedule for raising the PEG concentration also gave their opinion that the borate concentration in the preservation solution should be raised to 3%. This was accomplished by adding 1500 kg of borax and boric acid as twentynine equal portions to the solution between May 1970 and March 1971. During that period, an average pH value of about 7.25 was maintained in the solution.

At the time when possible bacterial decomposition of PEG was suggested, the necessity of providing a final protection of the surface of the hull from microorganisms and fungi was pointed out. It was suggested that this should be accomplished by raising the concentration of borates in the preservation solution during the final treatment of the hull. For this reason, 2200 kg of borax and boric acid were added to the preservation solution as sixteen equal portions between October 1973 and August 1974, which raised the concentration of borates, calculated as boric acid, to an average of about 1.5% during that period of time. The addition of borates also raised the pH value of the solution to about 7.5 during that period.

It should be noted that during the period when few or no increments of borates were added to the preservation solution, the borate concentration scarcely fell below a level of about 1% (figure 4-19) which may presumably be regarded as an equilibrium level with the borates in the wood.

period	Borates as boric acid %		pH of the preservation liquid	
	max.	min.	max.	min.
1965	4.19	1.98	7.36	6.10
1966	3.56	1.85	7.41	6.77
1967	2.13	1.26	7.15	6.09
1968	1.68	0.84	7.13	6.09
1969	1.17	0.86	6.60	5.85
1970	1.38	0.91	7.67	6.33
1971	1.41	0.92	7.43	6.82
1972	1.36	0.93	7.02	6.68
1973	1.83	1.02	7.56	6.74
1974	1.95	1.36	7.53	7.01
1975	1.84	0.95	7.37	6.64
1976	1.46	1.02	7.12	6.43
1977	1.55	0.87	7.08	6.37
1978	1.51	0.97	6.83	6.10

Figure 4-19 Concentration of Borates calculated as Boric Acid and pH Values in the Preservation Liquid

Consumption of Boric Acid and Sodium Borate

The highest solubility of borates in a PEG 4000 solution in water was achieved by mixing 7 parts of boric acid with 3 parts of borax, which had been found by solubility investigations made by the research and analysis laboratory of the Vasa conservation department. When PEG 1500 was substituted for the 4000, these proportions were maintained. The borate content of the solutions was determined as boric acid. This means that the separate consumptions of boric acid and borax could not be determined, and that the total consumption had to be calculated as boric acid.

Of a total of nearly 15 tons, 10.5 tons were consumed during the first two years of treatment and the rest during the 1970 - 71 and 1973 - 74 periods when increments of borates were added to the solution with 1.5 and 2.2 tons respectively (figure 4-18).

Antifoaming Agent

When the spray system was started, a substantial amount of foam was produced that somewhat impaired the drain back to the tank of the preservation solution (figure 4-20).

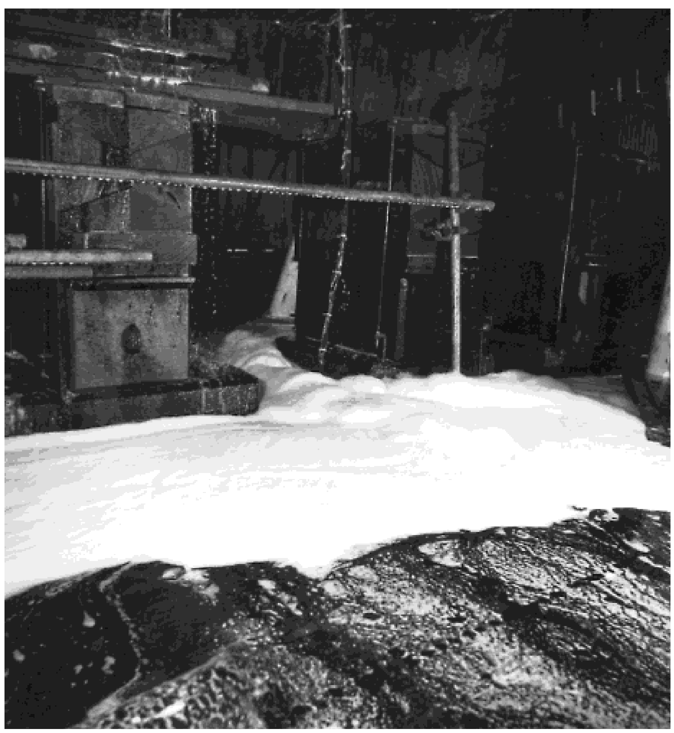

Figure 4-20 Foam on the top plane of the pontoon produced by the spraying of the preservation liquid (photo: Göran Sallstedt)

The foam production might also have become an obstacle to the diffusion of the preservatives into the wood (figure 4-21). To get rid of the foam, a silicone product (18) was added to the preservation solution.

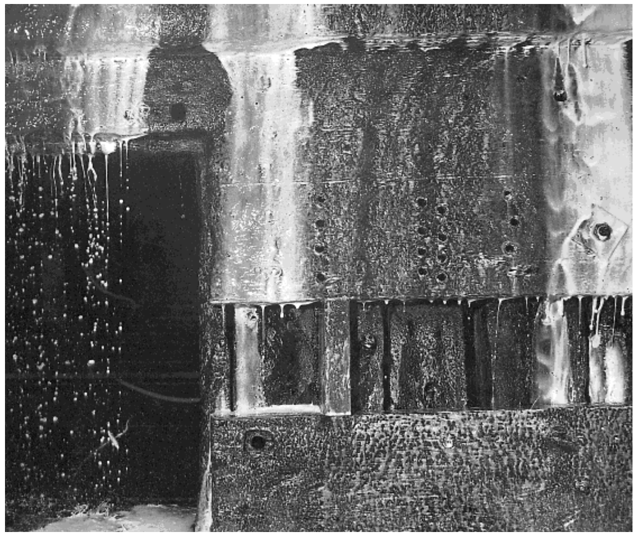

Figure 4-21 Foam on the surface of the hull produced by the spraying of the preservation liquid (photo: Göran Sallstedt)

At the Conservation Council meeting on 29 April 1965, Barkman reported that the anti-foam effect of the product lasted for only a couple of days. The concentration of the anti-foam emulsion in the preservation solution was set to be 100 ppm. It was however pointed out that repeated small increments would become a substantial amount over the years. The Conservation Council therefore recommended that no more anti-foam agent should be added to the preservation solution until the effects on the wood and the preservation process had been investigated.

At the next Conservation Council meeting, Barkman reported that there was no longer any problem with foam. As the anti-foam agent was not needed, the investigation into the effects of the product could be abandoned.

After that, only a small amount of about 2 litres of the anti-foam agent was added in the autumn of 1970.

The total amount of anti-foam emulsion added to the tank was less than 35 kg which corresponds to less than 1400 ppm calculated on the amount of preservation solution in the tank during that period of time.

Monitoring the Preservation Solution

For the spray system to function properly, a minimum volume of preservation solution had to be present in the tank. During the spraying activity, most of the solution returned to the tank but some of it was adsorbed onto the wood surface and so was held back from circulation. Water would also evaporate from the circulating solution, and this affected both the volume and the concentration of preservatives in the solution.

To obtain information to enable the solution to be adjusted so as to keep the necessary volume, the tank was sounded twice a day. Twice a week, samples of preservation solution were removed from the tank. The samples were analysed for PEG and boric acid. Density and pH value were also determined. The main reason for keeping track of the pH value was because it had to be kept within limits so that the preservation solution did not become harmful to the wood. The pH values however also gave a clue to the actual proportions of boric acid and borates, and this was of guidance when adjusting the solution. The figures from the sounding, the density of the solution and the concentrations of PEG and boric acid were used to calculate the actual amounts of preservatives in the tank and from these the proper composition of the solution needed to adjust the volume.

Handspraying Treatment after Closing down the Automatic Spray System

The second part of the spray period that started at the beginning of 1975 aimed at reaching a point when the spraying could be stopped. At the Conservation Council meeting on 16 October 1978, Lundström raised the issue of surface treatment of the hull after the spraying had been stopped. Rånby had recommended that the final treatment should be executed with PEG 4000. However, because of the experience with the loose objects there was some apprehension that the PEG might create a thick coating which could only be removed by hot air. This might be avoided by using handspraying. The automatic spray system would also need some 10 tons of PEG extra to be able to perform the spraying (57). This would create additional costs that might equal the cost of extra personnel for the handspraying.

Surface Treatment of the Long Boat as a Pilot Project

To get some experience, treatment of the long boat as a precurser to the treatment of the entire hull was recommended by the Conservation Council (114). It was decided that the long boat should be treated by hand spraying with PEG 4000 solution. The sprayings were to be repeated once a week and they were to be stopped as soon as there were signs of solid PEG on the surface. This happened after four coatings. However, as the relative humidity in the pontoon superstructure was between 65 and 70% with 70% at the lower levels where the long boat was situated, the drying situation was not the same as was planned for the hull. To create a climatic situation similar to that planned for the hull, a plastic tent was raised around the long boat. To lower the relative humidity, the temperature in the tent was raised. The progress of the drying of the long boat was to be followed-up by analysing core samples.

To establish the moisture content at the start of the treatment, one set of cores was taken in October 1978. Another one was taken in the summer of 1979 to reveal the impact of a six months drying period. A piece of information from the two core samples was that the PEG-ratio was substantially higher than had been achieved in the much heavier timbers of the Vasa hull. The moisture ratio had dropped between seven and twelve units down to a level of between 20 and 30 % in the interior of the wood during the test period.

Closing down the Automatic Spray System

At the meeting on 13 December 1978, the specialists on the Conservation Council decided to recommend that the possibility of reducing the relative humidity of the air in the Vasa hull to between 70 and 75% should be investigated, that the spraying of the hull with PEG 600 should be stopped and that the surfaces of the hull should be thoroughly supervised for an observation period of three months, so that it would be possible to react to any surface checking that might occur. The Conservation Council also took a decision that they would give a recommendation about the finishing surface treatment after the three-month observation period after the automatic spraying was stopped.

In accordance with this recommendation, the board of the Swedish Maritime Museum took the decision that the automatic spray system was to be stopped. The museum director issued a written order to that effect. This was executed on 22 January 1979.

Test Treatment

The question of how to perform the surface treatment was thoroughly penetrated at a meeting of the Conservation Council (117). The feasibility of using the automatic system was examined in contrast to using hand-spraying. The matter was settled by the museum director who pointed out that there was a risk that the automatic spray system might lead to too large a surplus of PEG on the surfaces and cause trouble when it would have to be removed. Therefore hand-spraying was the only acceptable method for the surface treatment.

At the meeting on 11 May 1979, the Conservation Council recommended a test treatment. Part of the ship's outer surface should be hand-sprayed with PEG 4000 solution, which was the surface treatment that had been used on the tank-treated disconnected specimens. The test treatment was performed on 22 May and consisted of spraying with 45% PEG 4000 solution and subsequent air drying. After drying, a minor part of the surface was treated with hot air so that the PEG was melted into the surface. On 7 June, the treated surface was inspected by the specialists and found to be satisfactory. It was decided to proceed with the test and to spray half of the already treated surface once more with 45% PEG 4000 solution. The other half would get two more spray treatments with this solution. An additional, not yet treated surface, would be treated with a 25% PEG 4000 solution.

On 3 July, the specialists again inspected the treated surface and remarked that it had a certain moist appearance. To cope with this, the recommendation was to lower the relative humidity in the pontoon superstructure. However, a fourth spraying with a 45% PEG 4000 solution was decided on for the part that had been treated three times before, and a programme of three to four sprayings as a finishing surface treatment started to take form, although the behaviour of the surfaces was to be carefully supervised so that any anomalies could be dealt with in time.

The Finishing Surface Treatment of the Hull

First Attempt at Surface Treatment

At the Conservation Council meeting on 3 July 1979, some differences in the capacities of different surfaces to absorb PEG solution were reported. The test treatment was however considered satisfactory and it was decided that the whole of the outside of the hull was to be hand-sprayed with a 45% PEG 4000 solution. This was performed on 6 and 7 December the same year.

Condensation Problems

During the subsequent winter period, condensation was noticed especially on the lower parts of the hull. This was reported by Lundvall and the situation was considered by the specialists at the Conservation Council meeting on 11 March 1980. The specialists judged that the disturbance was due to faults in the climate and that the surface treatment could not be performed until those faults were remedied.

It was however difficult to decide when the climate had been ameliorated. The situation called for some method to investigate the condition of the wood surfaces. To achieve this a programme for evaluating the moisture situation of the wood by systematized touching of the surfaces was developed.

To be able to record the information, a system of notations for characterizing the wooden surface was invented. The chosen notations were "dry surface", "slightly moist surface", "moist surface", "slightly wet surface" and "wet surface". This series of notations was used for investigating the wooden surfaces by systematized touching. In this procedure, each part of a selected area was investigated.

A schedule for performing the investigation was developed, taking into account the possibility of reaching the selected parts of the hull. On those grounds, the lower parts of the hull from the keel up to the lowest wale on both the starboard and port side were chosen. This meant up to four metres above the keel plane. A horizontal beam of the steel cradle divides the areas on each side into parts situated lower and higher up. This beam thus constitutes an obvious border line The surface areas below and above the beam were separated each into eight fields using the standards of the cradle as border lines. Thus thirty-two areas for investigation were created (figure 4-22)**.**

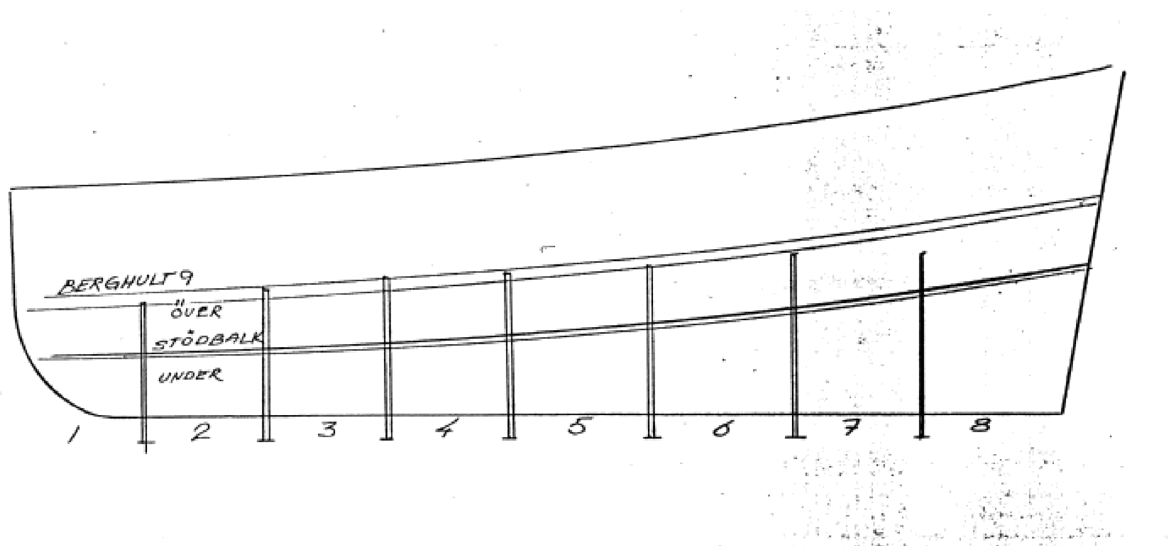

Figure 4-22 The port side of the Vasa hull with its sixteen areas for investigating the surface of the wood

The surface areas were investigated from the end of January to the middle of February 1981 and also in December of the same year.

In December 1986, the areas designated "number five" above and below the horizontal beam on the starboard side of the hull were selected as representative of the lower parts of the hull. These areas were investigated weekly to monitor the condition of the surface. This was done throughout 1987.

Resumed Surface Treatment

The year 1980 was devoted to an investigation of the climate in the pontoon superstructure. No second attempt at surface treatment of the hull was made. To compensate for the PEG washed away by the condensation, the lower parts of the hull were instead treated with the original conservation liquid with PEG 600 by hand-spray. This was performed twice in January 1981.

In March 1981, the Conservation Council judged it possible to carry out surface treatment of the upper parts of the hull down to the condensation area (129). The starboard side of the hull was spray-treated during the month of April. After a short drying period of one month, the heat treatment to melt the PEG 4000 into the surface was also accomplished (figure 4-23). The result had been inspected by Rånby, who gave his opinion that the result was excellent (130).

Figure 4-23 Melting PEG with a hot air blower (photo: Sven Bengtsson)

The corresponding treatment of the port side of the hull was planned for September of the same year. The investigation of the surface condition made in November 1981 revealed however that the condensation situation was not quite stable. The treatment of the the upper part of the portside was therefore postponed until the spring of 1982.

The same surface treatment was given in 1983 and 1984 (133, 135) to the surfaces inside the Vasa hull that could be reached from the deck compartments in contact with the surrounding atmosphere. However, the melting of PEG into the surface was performed only down to the upper gundeck, for safety reasons when handling the hot air blower.

The moisture content of the wooden structures of the deck compartments with no contact with the surrounding atmosphere was still too high for surface treatment. Closing down the automatic spraying however caused the drying to accelerate even in those spaces. To slow down the rate of drying and to increase the PEG uptake of the heavy timbers in the hold and orlop deck compartments, a first round of handspraying with PEG 600 solution was carried out in February 1980. The treatment was repeated twice during the summer of 1980 and also in January 1981. This was sufficient until 1982 before another round of treatment was needed. In 1982, two treatment rounds were performed, one in April and one in August. A final treatment round was carried out in 1986 when special measures were taken to accelerate the drying of the timbers (chap. 5).

This also affected the oak deckplanks that already in 1977 were ahead of the rest of the timbers in drying (chap. 7). In 1986, some of the deckplanks, especially on the upper and lower gundecks, showed a slightly concave surface that indicated too rapid drying. To counteract this, all the deckplanks that could absorb conservation solution were treated each week throughout 1986. When the deckplanks could absorb no more conservation solution, the decks were covered with plastic sheets to keep moisture in the wood for as long a time as was needed for the deckplanks to reshape and to promote drying from the undersides of the planks. It then was not until 1991 when another round of treatment of the deckplanks was considered necessary.

Surface Treatment prior to Moving into the Permanent Vasa Museum

In 1987, a round of spray treatment with PEG 4000 was finally executed on the lower parts of the hull, ending up with the test surface at the end of November. The final surface treatment had to be finished before construction of the transportation encasement started.

In response to a recommendation from the chairman of the Conservation Council, the finishing treatment including the melting of PEG into the surface was to be repeated twice to ensure that the outermost PEG layer could easily be stripped away to remove dirt from the hull after it had entered the permanent museum building (139). At each round of treatment, the spraying was to be performed as many times as was needed to build up a surface layer of PEG 4000. In the melting process, any surplus of PEG was removed (figure 4-23).

There was a 24 week plan for the execution of the whole of the final treatment. Because the preparations for moving the Vasa hull were due to start on 8 August 1988, the treatment work had to be started early in 1988. Its completion was reported to the Conservation Council on 24 October (140).

Surface Treatment in the Permanent Vasa Museum

The construction work had not been finished when the transportation encasement was opened in the summer of 1989 and, because it was not closed again, a lot of dust fell on the Vasa ship during the winter of 1989 - 1990 while the museum building was being completed (figure 4-24).

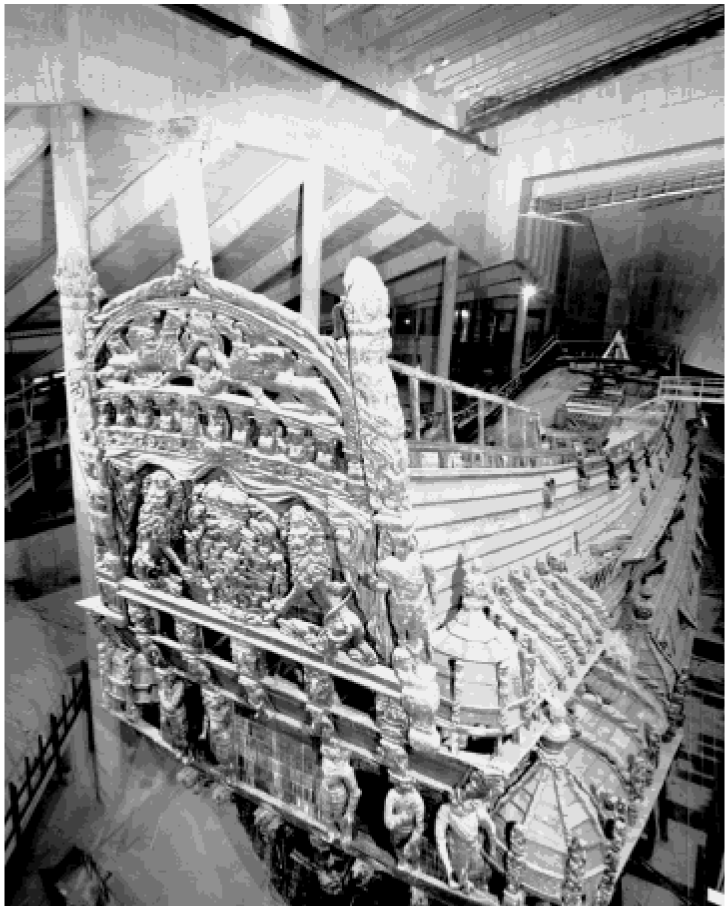

Figure 4-24 Vasa covered in dust produced by construction work (photo: Gunnel Ilonen)

It was obvious that the Vasa had to be cleaned before the museum opened to the public in the middle of June 1990. To perform this work, scaffolding was put up around the Vasa hull and four additional conservator assistants were hired. Since the stern part with its huge amount of sculptures was calculated to be the most time-consuming part to deal with, the scaffolding was first placed around the stern (figure 4-25). The work went according to a programme with dust removal as the first item. This work was done with vacuum cleaners (figure 4-26). After this dry cleaning, a gentle cleaning with a slightly moistened genuine sponge was undertaken in order to remove the dirt that stuck to the surface (figure 4-27). This procedure also removed some of the PEG. The next item was application of PEG-solution to the surfaces (figure 4-28). This was done to the sculptures using a paint brush and to the general surfaces by spraying. The PEG application was performed as many times as was needed to achieve a sufficient surface protection. The last stage was to melt the PEG into the surface of the wood and remove any surplus of PEG (figure 4-23).

The work on the stern took the whole of the planned period of three months. The scaffolding was then moved to the beakhead part of the ship. This was a working place that was somewhat nearer to the ground. Although the beakhead is adorned with many important sculptures, the work was completed in half the time required for the stern.

Figure 4-25 Work on the surface of the hull from a hanging work platform and scaffolding (photo: Sven Bengtsson)

Parallel to the work with the heavy sculptured fore and aft parts of the ship, the sides with their rows of gunports adorned with lion masks were treated separately by another work team. Most of the work was performed from a hanging platform (figure 4-25). Apart from the lion masks, about 1200 square metres of the ship´s sides had to be cleaned by hand. Although the PEG application was done by spraying, the heat treatment to get rid of the surplus was done by hand from the rather unstable hanging platform.

Dust however continued to fall onto the ship. To gain information as to its origin, dust was collected on glass plates placed fore and aft of the upper deck of the ship during the summer of 1991. The analyses provided the information that half the dust particles were organic textile fibres and the other half were inorganic particles. About twenty per cent of the inorganic material might come from the cement of the museum walls, while the rest was identified as dust brought in from the street, presumably by visitors whose clothes might also have provided the textile fibres (57).

Figure 4-26 Removing loose dust with a vacuum cleaner (photo: Sven Bengtsson)

Figure 4-27 Cleaning the dirty surface with a moistened genuine sponge (photo: Sven Bengtsson)

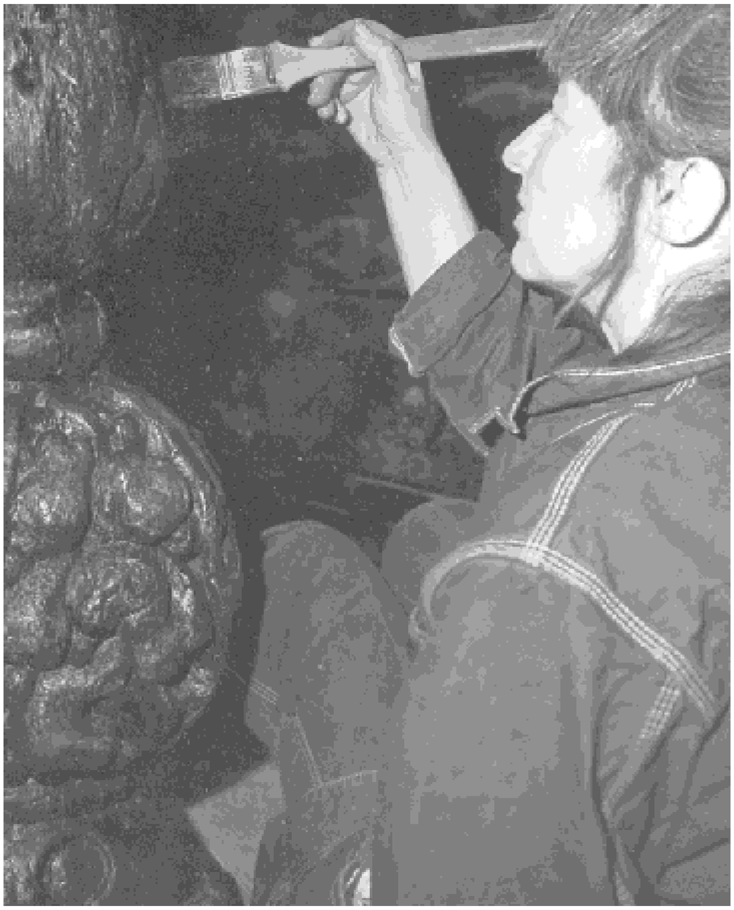

Figure 4-28 Application of PEG-solution to the clean wooden surfaces (photo: Sven Bengtsson)

It was obvious that the removal of dust from the ship must be a recurrent item on the Vasa maintenance programme. That would mean a certain wear to the surface. It was however decided that the ship was to be cleaned for a second time during the winter and early spring of 1992. To cause as little damage as possible to the wooden surfaces, it was decided that dry cleaning was to be the main procedure. PEG would be added to the surfaces only if absolutely necessary. Hot air would be used only if a surface had been subject to moisture or a new PEG coating.

After the work had been finished, the work team gave its opinion that the use of a more moist cleaning would have been preferable to get rid of the dirt. However, the avoidance of wear of the surfaces as much as possible was adopted as the policy of the Vasa museum.

Chapter 5

DRYING THE HULL

Drying as part of the conservation programme was brought to the attention of the Conservation Council, as early as their second meeting in May 1961 when Thunell gave a brief outline of how the process was to be performed. He emphasized that spraying of the hull with water had to be continued until the superstructure had been completed. After that, the humidity of the air ought to be controlled so as to achieve an even drying process parallel to the treatment (79, §8). For this to be achieved, an air-conditioning system was necessary.

Later the possibility that a properly conducted drying process might have a beneficial influence on the overall shrinkage was emphasized by the Conservation Council (101).

The requirements of the system could be expressed as proper temperature of the air, proper humidity of the air and proper air circulation. The three parameters were of somewhat varying importance during the different preservation periods and for the long-term conservation of the finished ship. This made it possible to choose different ways to solve the air-conditioning problem during the different preservation and long-term conservation periods.

Air-conditioning Systems 1962 - 1988

To operate the spray systems for the preservation treatment and to humidify the atmosphere of the pontoon superstructure, a compressed-air unit with a working pressure of 7.0 atmospheres (bars) was ordered (39) by the Board of the Vasa at the beginning of November 1961. The unit could produce 4.0 m^3 free air per minute.

The unit was installed in a special onshore building. From the building, the pipeline crossed the bridge between the pontoon and the Vasa museum site and then went further into the pontoon superstructure. The installation could not however be put to work until the pontoon superstructure was completely finished and the heating had been started. The water spray of the Vasa was therefore continued in the winter until there was a danger of ice forming on the pontoon which might have caused it to sink. The water spray then had to be stopped.

The remaining installations were completed in February 1962 and the air-conditioning consisting of heating, humidifying and circulating the air was started.

Heating

The heating system of the pontoon superstructure consisted of two hot-air units (40) placed on the pontoon, one in the corner facing the starboard fore part of the hull and the other in the corner facing the port aft part of the hull. This hot-air heating plant was in operation during the whole of the period in the pontoon superstructure, i.e. from 1962 until December 1988.

The boiler and oil tank were placed in a separate building ashore.

Air Circulation

During the period from 1962 until 1972, the blowers of the hot-air units were the sole means of air circulation in the pontoon superstructure. The blowing capacity of each unit was 7400m^3/h and they were fed by air taken from inside the building at the corner in which the unit was situated. The units were rebuilt to be constantly blowing air regardless of whether heating was required.

There were no means of actively and in a controlled way bringing outside air into the building, so the only way in which outside air came in was through leakage through the entrance doorways and leakage of the construction.

To prevent any draught from the working entrance situated on the bottom level of the pontoon superstructure at the starbord fore part of the Vasa from having a damaging effect on the hull, the ventilation duct blowing air from the nearby hot-air unit was extended in the doorway area.

Water Spray System 1962 - 1968

In the pontoon superstructure, there was a pipeline installation for humidifying the atmosphere. To serve the upper part of the pontoon superstructure there was a pipeline in the middle of the roof in the longitudinal direction of the building and to serve the lower part there were two parallel pipelines mounted on the underside of the lower visitors´ gallery, one on the starboard and one on the port side of the hull. The pipeline was equipped with spray nozzles. There were also some strategically placed spray nozzles, for instance in the air stream from the blowers of the hot-air units. The plant was fed from ashore with tapwater that was mixed with compressed air to give a water mist in the atmosphere.The system was intended to maintain a relative humidity of nearly 100%. Barkman wrote in June 1962 that the air-conditioning system consumed 23 m^3 of water per 24 hours (38). The total volume of the pontoon superstructure including the volume of the Vasa hull was 15 000 m^3.

The water spray plant was in operation from early 1962 until the middle of January 1968. From the middle of March 1965 until the beginning of 1972, the automatic preservation spray plant was keeping the entire hull constantly wet and this also added to the humidity of the air. The water feed to the air-conditioning system was immediately cut down to two m^3 per 24 hour period when the preservation plant was started. After four months, the water feed was gradually reduced, first to 500 litres and after another three months to 250 litres per 24 hour period. For the rest of the time during which this air-conditioning plant was in operation, similar small amounts of water were consumed. During the latter part of the intensive spraying period, no extra humidity was added.

Water Vapour System (steam) 1972 - 1988

During 1970, the schedule for bringing down the intensity of the spray treatment was discussed. That again brought the question of air conditioning in the pontoon superstructure onto the agenda of the Conservation Council. On 10 September 1970 (97), the chairman informed the meeting that the museum director had written a letter (42) to the National Board of Building and Planning requesting that the air conditioning of the pontoon superstructure should be dealt with before the end of the intensive spraying period that was planned for the autumn of 1971.

There had already been two meetings with representatives for the National Board of Building and Planning which had brought in a consulting firm (154) whose representatives Prof. Allander and Broddling, who was an engineer, attended the meetings. The Vasa museum was represented by the museum director, Per Lundström and the chairman of the Conservation Council, Bertil Thunell. The latter specified the working range for the system. It should be adjustable between 60 and 80% relative humidity at about "room temperature". This would also apply to the atmosphere inside the Vasa hull.

Some tolerances in the fluctuations of the relative humidity and temperature were mentioned. For a 30 day period those fluctuations should be small, during a 10 day period larger differences were allowed, and during one day and night period rather large discrepancies could be overlooked. No figures for the magnitudes of the discrepancies were however mentioned.

The conditions created by the pontoon superstructure were not favourable for making a water vapour installation work. After some discussion, the Conservation Council recommended that the museum should request a technical and economic investigation from the National Board of Building and Planning concerning the possibilities of creating the requested climate.

At the first meeting in 1971 of the Conservation Council (98), Allander and Abel (154) presented a scheme for air conditioning the pontoon superstructure at a moderate cost. The installation would work with steam and would circulate air at a flow rate of 35 000 m^3 per hour.

At the meeting of the Conservation Council on 18 April 1972, Barkman reported that the air-conditioning installation had been set to work.

The installation consisted of one low pressure steam boiler that was placed in a separate housing on the pontoon outside the pontoon superstructure. The boiler could produce 170 kg of steam per hour. In each of the corners not occupied by the hot air units a large continuously working recirculating blower was placed. The steam was distributed into each blower by a steam valve that could handle as much as 75 kg of steam per hour. The damp air was then distributed by the blowers into two ventilation duct systems along the sides of the hull fairly close to the wooden surfaces at a height of 2.5 m above the pontoon. The air outlets were directed so as to be able to sweep the wooden surfaces with the outcoming air. Another duct from each system was distributing air into the hold through ten ramifications, each 200 mm in diameter, leading into the hold.

Thunell suggested that the outlets might incorporate some arrangement for diffusing the air instead of the narrow air jet produced by the outlets of the installation (100). The air ducts with outlets of the system outside the hull were also blowing directly on to the wooden surfaces of the hull. The installation had to be rebuilt. The main ducts were moved to a position near to the walls of the pontoon superstructure. Every second outlet was directed upwards and the others were directed downwards.

At the meeting of the Conservation Council on 27 February 1973, Barkman reported that the relative humidity in the pontoon superstructure was still so high so that no added moisture had been needed. The air-conditioning installation had functioned only for air circulation during the winter of 1972 to 1973.

Development and Expansion of the Water Vapour (steam) System

For interior ventilation, the installation of 1972 had provided only a duct system for air circulation into the hold. The orlop deck compartment had no ventilation at all. At the meeting on 25 June 1975, Håfors pointed out that ventilation of the orlop deck was needed to achieve an even drying of the hull. Lundström suggested that a remedy would be to make a connection between the orlop deck and the hold by temporarily removing some of the deckplanks. This was not however done. Instead, the ducts of six of the outlets in the hold were extended to reach into the orlop deck compartment. Moreover they were fitted with T-shaped heads that could distribute air in two directions. The installation was made in the autumn of 1975.

The drying process in the hold and orlop deck compartments was however retarded compared to that of the rest of the hull and was still very slow. The reason for this might be that the moisture fed into the common air-conditioning system was adapted to the needs of that part of the hull that was in direct contact with the atmosphere of the pontoon superstructure. This meant that too much moisture was being brought into the closed compartments in the Vasa hull.

Schoerner who had looked into the situation together with BS Konsult reported to the Conservation Council on 22 November 1976 (110). He put forward the suggestion that the duct systems for the hold and orlop deck should be separated from the outside systems. The inside systems should have their own mutual blower that was to take air from the atmosphere of the pontoon superstructure. Even if extra humidity was not expected to be needed, the installation would include a moisture unit. The Conservation Council recommended that the changes in the installation should be executed promptly so that the plant could be put into operation on 1 May 1977 at the latest.

On 5 August, Håfors reported to the Conservation Council (112) that the climatizing installation for the hold and orlop deck had been put into action on 31 May, but that the installation was still without a humidifying unit. Lundström reported that he and the chairman had inspected the installation on 20 June. They had judged the air flow to be too feeble. After having measured the air flow and having found that it was 5000 m^3 per hour, they had increased the air flow to 12 000 m^3 per hour by removing the narrow part of the entering air duct. The humidifying unit was installed later, but it was not put to work until March 1981 (127).

Regardless of the improved air flow, Barkman reported to the Conservation Council on 9 December 1977 that it had not been possible to lower the relative humidity of the hold and orlop deck to 65% that had been set as a goal (113). About a year later, the leveling out of the climate had been achieved (114, §4).

Added Air Circulation Systems 1980 - 1988

After the automatic preservation spray system had been closed down in January 1979, the intention was to treat the wooden surfaces by hand spraying with a water solution of PEG 4000. The first test to see whether the wooden surface could absorb the PEG solution was made on 22 May 1979. This performed as anticipated and in December the entire hull was treated (120 & 121). However, it was reported by Lundvall that condensation had appeared on some of the surfaces. As a result, the members of the Conservation Council visited the pontoon superstructure on 12 December in order to inspect the situation. It was obvious that something had to be done, so it was decided that Allander was to be called in to investigate the situation (122).

To get some idea of why there was water condensation on the wood, Allander had his doctoral students Kenneth Lindqvist and Bengt Ljungqvist make a series of temperature measurements on the surface of the wood and in the surrounding air. On 11 March, they reported to the Conservation Council (123, §6) that they had found a temperature difference of 2°C, which would mean a situation around the dewpoint at the temperature and RH-level in the area. They also measured the RH to be between 88 and 93% and judged that there was no air movement to be observed.

It was obvious that the climatic situation in the pontoon superstructure did not meet with the requirements for surface treatment and for conducting a proper drying process. At the meeting of the Conservation Council on 23 May 1980, the museum director reported that the National Board of Building and Planning would need one year to look into the problem. The Conservation Council thought this too long and that the present situation had to be ameliorated very soon, so as not to endanger the achieved state of conservation of the Vasa hull.

Discussion during the autumn resulted in the construction of two large recirculation systems for the east and west sides of the pontoon superstructure respectively (52). The measured flow of each of the units was about 9000 m^3 per hour. Both took air at the level of the upper visitors' gallery and distributed the same air underneath the Vasa hull through about twenty outlets on a main duct on the east and west sides in the pontoon superstructure. The outlets had special attachments that were adjustable in any direction. The installation was made at the end of 1980. At the same time, the ventilation duct from the hot air unit at the port aft part of the hull was extended some ten metres.

Despite the added circulation units, the Conservation Council on 21 January 1981 (126) declared that the air circulation in the building was not satisfactory. The relative humidity showed mean values of between 70 and 78%. Condensation on the hull in the beak-head (161) region in particular showed that the air circulation was not satisfactory in that part of the pontoon superstructure. The need to make the drying process proceed was also discussed. There were some differences about the preferred RH-level for the drying process. Rånby held the position that 65% RH-level was suitable, whereas Thunell preferred a slower drying rate and recommended 70% RH.

After a visit to the pontoon superstructure, two measures were recommended by the Conservation Council in order to prevent condensation on the hull. The first was to move the hair hygrometers to the zone where the condensation was noticed to start. The second was that a small air circulation unit should be placed at the lower visitors´ gallery that would take air from the ventilated zone and distribute the same air around the beakhead.

Special Arrangements during Low Temperature Periods of the Late Phase of Conditioning in the Pontoon Superstructure

The climate in the pontoon superstructure continued to create problems for the status of the Vasa wood and for the drying process. In June 1985, Thunell wrote in a memorandum (54) referring to a report from Håfors (53) that the maintenance of the temperature and relative humidity in the pontoon superstructure had been far from satisfactory. During the years 1983 and 1984, high RH-values had been parallelled by low temperature values, and low RH-values had prevailed during periods when the temperature was high.

He pointed out that "this is contrary to the demand that the conditions should keep a constant equilibrium moisture rate in the wood and leads to disturbances of the drying process and tension in the wood with inhanced danger of cracks, deformation and peeling off from the surface of the wood". In the memorandum, Thunell made a request to the National Board of Building and Planning to add to the temperature installation so that a lowest temperature of 12°C could be maintained during the winter. To achieve this, four loose heating blowers, each of 10 kilowatt, were placed in the pontoon superstructure from December 1985 to maintain the desired temperature level during low temperature periods.

Climate Control in the Pontoon Superstructure

The water spray system that worked from 1962 to the middle of January 1968, i.e. through the hand spraying period and also during the first part of the intensive spraying period, had no control system but worked 100% at the preset level. During the latter period of intensive spraying of preservation liquid from the middle of January 1968 to the beginning of the 1970’s, no air-conditioning system was working.

The water vapour (steam) system that was installed in 1972 was controlled by hygrostats in the ventilation ducts. Barkman had from the beginning doubted the adequateness of this because the hygroscopic polyethylene glycol could contaminate the hair sensors of the hygrostats. He therefore wanted the hygrostats to be encapsulated and placed in the space that was to be climatically conditioned and not in the ventilation ducts. This he had pointed out in a letter to the consulting firm (154) in March 1972 (43). His misgivings were verified when the installation worked at full effect during the summer of 1972 and caused condensation on the hull. Discussions with Allander (154) resulted in the idea of filtering the air before it reached the hygrostats. In November 1972, Barkman wrote to the National Board of Building and Planning to request changes in the air conditioning installation to make it work properly (44). One measure was to move the two hair-type hygrostats from the ducts into the climatized space. A special box was also constructed for the hygrostats with a filter and a blower (45).

When the intensive spraying period was coming to an end, the question arose as to what level of relative humidity was to be preferred in the pontoon superstructure. In March 1972, Barkman reported on research at the conservation laboratory (37) into the equilibrium between Vasa wood treated with PEG 4000 and untreated Vasa wood in climates of different relative humidities (99). It was clear that the equilibrium moisture level in the material treated with polyethylene glycol was higher than it was for the untreated material in the same climate. The research had also shown that the hygroscopicity of PEG 4000 was such that it could take up so much water at 85% RH that PEG was actually leached out of the wood. The recommendation was that the relative humidity in the pontoon superstructure should be lowered to 80 % for a period of two years after the air-conditioning installation had been put to work.

In March 1975 (104), when the programme for finishing the spray treatment was discussed, Rånby suggested that the relative humidity that was held at a level between 80 and 85% should be gradually lowered to 65 % for a period of one year at the same time as the spray treatment was reduced. This suggestion was expressed as the recommendation from the Conservation Council and Barkman was charged with the task of working out a programme to be approved by Rånby. The programme was presented to the next meeting of the Conservation Council on 25 June 1975 (105). The Conservation Council recommended that the 75% RH-level be kept as a first step until the next meeting.

The relative humidity in the pontoon superstructure was not discussed again by the Conservation Council until November 1976 (110) when there was a check-up on the conservation programme. The meeting noted that the relative humidity had varied between 70 and 75%, with 75% as the current value. In March 1977 (111), the relative humidity was discussed at the meeting of the Conservation Council. It was stated that the relative humidity was 75% in the pontoon superstructure, but as much as between 80 and 90% in the hold and orlop deck compartments. The Conservation Council members present at the meeting expressed concern that they had not been informed about this extensive difference between the outside and inside of the hull. The meeting also regretted that the recommendation to lower the level of relative humidity to 65% had not been followed and insisted that this should be done immediately. The levelling out of the climate between the outside and the inside of the hull should be brought about by speedy installation of a new air-conditioning equipment.

The proposal to lower the relative humidity in the pontoon superstructure was put into action by adjusting the control values of the two hygrostats to 65%. In December 1977 (113), the Conservation Council observed that this measure had given RH-levels of 65 to 70% in the pontoon superstructure during the summer and 70 to 75% during the winter. Figures reported to the Conservation Council in October 1978 (114) showed that the new climatizing unit with added air circulation for the inside of the Vasa hull, that had been working since June 1977 had achieved the desired levelling out of the climate between the outside and inside of the Vasa hull.

After the close down in January 1979 of the preservation system, the air-conditioning was the sole means of controlling the drying process. Two weeks after the closing down of the spraying system, Håfors reported to the museum director that the relative humidity outside the hull remained between 65 and 70% but that it had dropped to below 70% in the hold. To remedy this, the added heat in the air stream to the inside system had been lowered from ten to five kilowatt. The meeting of the Conservation Council on 23 February 1979 responded to this by recommending that the relative humidity should be kept at about 70% (116). In May 1979, the judgement was that the RH both of the pontoon superstructure and inside the Vasa was even and at a satisfactory level. According to records kept over one year (118, app 1), the

RH-level inside the hull stayed a couple of units above 70% while the RH outside stayed between 65 and 70%.

Towards the end of 1979, however, condensation was noticed on the Vasa hull and in May 1980 (124) Håfors reported differences in mean values of as much as seven RH units between the two-metre and the eight-metre levels above the pontoon in the pontoon superstructure during the period from January to May 1980. To achieve a more even RH-distribution and to cope with the problems of condensation, the previously mentioned expansion of the air-conditioning and air-circulation systems was necessary but not sufficient. To even out the relative humidity over time and in the space of the pontoon superstructure, the control equipment had to be placed properly. After consulting BS-konsult in February 1981, their expert, Sandor Faxvall looked into the problem and suggested that the hygrostats should be placed at the level where the condensation started (127). The Conservation Council came to the decision that the hygrostats should be adjusted so that the mean relative humidity both inside and outside the hull would be equal to 72%. Because the RH-level inside the hull had dropped to as low as 67%, this meant that steam was to be added to the inside system for the first time. A large difference between the temperature of the starboard and port sides of the Vasa hull had also been noticed, especially when the sun was shining on the poorly insulated southwest wall of the pontoon superstructure. Allander suggested that a test with free blowing blowers to level out the temperature difference should be performed, but this was never done (128).

In January 1983, the Conservation Council decided that the RH-level should be lowered by two units to 70%. This RH-level was held for about two years. In January 1985, the Conservation Council found that the drying had not proceeded as expected. Since this could be attributed to the low temperature during the winter, it was requested that the lowest temperature for the next winter would be 15°C.

Moreover, in order that the drying process would not come to a standstill during the winter period, Thunell worked out an equilibrium diagram for the desired moisture ratio. This diagram suggested a lower moisture ratio level than before, because the RH-level at 20°C was put to 66%. This was just a little higher than the intended long-term climate for the new Vasa museum. In September 1985, Thunell put forward a list of three measures that had to be observed during the winter. They were, as before, that the temperature must be kept at least as high as 15°C. The new remedy was that the hygrostats were to be adjusted in accordance with the equilibrium diagram. The mean values of RH and temperature were to be read from the thermohygrographs and compared with the diagram as feedback every week.

This programme was adopted. This meant that from November 1985 and for the rest of the period in the pontoon superstructure and the temporary encasement, the temperature near to each of the three hygrostats was checked and the hygrostats were adjusted in accordance with the diagram every day. The weekly feedback was followed up by the chairman of the Conservation Council.

However, the pontoon superstructure was worn down by having been in use for more than twenty years instead of the expected ten to fifteen years. This also meant that the drying process had come to a state in that building for which it had not been planned. In February 1986, a request was made to the National Board of Building and Planning stating what measures the Conservation Council judged to be necessary to improve the climate of the building. The National Board of Building and Planning was obviously not interested in investing any money into the pontoon superstructure and found the request unrealistic presumably because the construction of the permanent museum was soon to be started. Thunell, the chairman of the Conservation Council, who had handled the contacts with the Board, called a meeting on 26 June 1986 especially to discuss this issue (138).

Thunell informed the meeting of the situation and after some discussion it was decided to state the wood science evaluation of the phase then reached in the drying process. This was summarized in four points. The first point stated that "the ship is now in its most sensitive transitory stage", the second point stated that "the parameters that have been set up by the Conservation Council (for the new museum (author's note)) are based on a stationary phase for the ship. The transitory course needs more exact adjustment of the climatic parameters than in the stationary state". The third point stated that "the Conservation Council has the impression from discussions with the National Board of Building and Planning that the Board´s intention is to base its actions concerning the superstructure on considerably less adjustability and stability of the climate than is justified by the state ((phase) according to the first point) of the ship". The fourth point said that "in setting up the claims, the Conservation Council has taken account of the interaction between heavy and light parts of the ship as far as thermal properties are concerned. The heavy parts, according to experience, are subject to condensation with the accompanying leaching of conservation substances, while the light parts have better adjustability and are in a better position to withstand those changes".

The meeting decided that the minutes from the present meeting together with a special letter of introduction from the museum director was to be forwarded to the Technical Director and several other representatives of the National Board of Building and Planning.

To be able to discuss upcoming problems of the pontoon superstructure as early as possible with the National Board of Building and Planning, there was a request from the Vasa museum that a representative from the Board should be charged with the task of taking part in the meetings of the Conservation Council. This was approved from March 1986 until the Vasa had been moved into the new museum in 1989.

The Air Conditioning System in the Transportation Encasement

The transportation encasement that was to protect the Vasa during the journey to the new museum site and during the first period in the half-built new museum was very narrow (Chap. 3) and yet it was to house sufficient installations to keep the climate as it had been in the last period in the pontoon superstructure.

To start with, the ducts for the steam air-conditioning system that were placed at the sides of the pontoon superstructure were removed and discarded. The steam units were instead connected to the duct system for circulating air from the high to the low levels in the pontoon superstructure. This system had its outlets from two large ducts below the Vasa hull on each side of the keel. The circulating function of the system was also preserved, but the duct system collected air from high levels a little closer to the Vasa hull than before. The special unit that brought air inside the Vasa hull was kept in function. This was fed by air from the atmosphere at the keel of the Vasa hull.

Choice of Values for the Relative Humidity and Temperature of the Permanent Vasa Museum

In the exhibition space in "Wasavarvet" in which from 1962 some of the previously preserved Vasa wooden objects were shown, the relative humidity was between 60 and 65 per cent as recommended by the wood experts in the Conservation Council. When the project of designing of a permanent Vasa museum was initiated in 1972, Barkman was commissioned to draw up the lines for what would be the necessary demands on the building from the standpoint of conservation (99). This would later be discussed by the Conservation Council. As no building project started, the project of defining those demands was not finished at that time. In 1981, however, the project of a permanent Vasa museum came back onto the agenda and the chairman of the Conservation Council (Thunell) again stressed the necessity of making the demands from the conservation standpoint clear at an early state, so that they could be incorporated into the architectual work (127, §7). The main concern was to create a suitable climate for the long-term conservation of the preserved ship. The basis for establishing the numerical values for the climatic parameters should be the preserved Vasa timbers.

The technical department of the National Board of Building and Planning, which was commissioned to work out the technical programme for the climate of the permanent Vasa museum, set up a special working team to deal with the task. The chairman of the Conservation Council was appointed as a member of that team. He thus was in a position to greatly influence the construction programme with his definition of the requirements for long-term conservation of the Vasa ship. This definition was "stability over time of the moisture ratio in every point of the wood and a defined moisture ratio level".

To discuss the programme for the museum climate, Thunell called an extra meeting of the Conservation Council for the 3 August 1981 (131). The meeting received a draft from the special working team dated 17 July 1981 to consider. The most important points were to stipulate the moisture level of the preserved Vasa wood and what influence on this would be allowed by the inevitable temperature gradient in the huge building. The draft mentioned 12 ± 1% as moisture ratio. As this way of expression gave the impression that the moisture ratio would be allowed to change up and down by 1 percentage unit, the upper and lower limits of moisture ratio were used instead. The highest moisture ratio was set to 12% and the lowest to 11%. The stable moisture ratio values between 12 and 11% of the Vasa wood would be achieved by keeping the vertical temperature gradient in the building within 2°C (131, §3, app).

The Air Conditioning of the Permanent Vasa Museum

Since it was a major monumental building, the Government decided that the construction of a permanent Vasa museum was to be preceded by an architectural competition. Such a competition was advertised on 7 December 1981 (132). The importance of the climate for the long-term conservation of the Vasa hull and wooden artifacts had been accepted. Therefore the technical equipment needed to maintain a stable climate on the level defined by the needs of the museum exhibit, the Vasa, was the most important item for the construction of the museum, and the architectural competition included the design of the air-conditioning system in the exhibition hall of the permanent Vasa museum.

The design of the air-conditioning system for the permanent museum started in 1985. The Conservation Council was able to follow and influence the work through Claes Allander who was to be consultant to the National Board of Building and Planning (136).

When discussing the chosen RH and temperature values with the construction companies, it soon became clear that this would make such demands on the construction materials that the costs for the building would exceed the given limits. The Conservation Council then reconsidered the situation and came to the conclusion that the moisture ratio level might be lowered by one unit to 10+1% without endangering the long-term conservation of the wood. This recommendation should be interpreted as permission for the moisture ratio in the PEG-treated wood of the different sections of the Vasa to lie between 10 and 11 per cent. However, in every point of the wood, the moisture ratio must be kept stable.

To bring about the desired situation, the temperature and relative humidity were given specific values and a control programme for the technical installation was created in order to maintain those values.

As there is no specification of the climatic parameters required to maintain the approved level of moisture ratio in the PEG-treated Vasa wood, recent spruce wood was chosen to establish the preliminary values. The higher moisture ratio of 11% was taken as a guideline, which means 60% RH at 20°C. The RH level is recognized as the main factor to control to keep the moisture ratio of wood stable. However, the influence of temperature must also be taken into account and a graph can be created with RH-values plotted against temperature values to show the relationship which gives a stable moisture ratio in the wood.

Again, because of the fear of damage to the building if 60% RH were maintained during the winter period, the 60% RH at 20°C pair was translated to 57% RH at 17°C by moving along the equilibrium graph to maintain an unchanged moisture ratio of 11% in fresh spruce wood, and this pair became the chosen control values for the winter period.

Air Circulation of the Permanent Vasa Museum

The total volume of the irregular museum building has been reported to be 105 000 m^3. This comprises the museum hall, the regular cinema and the combined cinema and lecture room in a more or less continuous space that in one way or other benefits from a common air-condition system, and also offices and workshops that are totally cut off from the museum in a separate space that is equipped with its own ventilation system. The volume of the museum space may be estimated to about 80 000 m^3. In the museum space, particularly the Vasa ship, the cinema and the exhibition space on the entrance floor are targets for air-conditioning measures.

Since the conservation of the Vasa ship is the reason for the extensive air-conditioning equipment, the ship is a special target for air-conditioning measures. To ensure a suitable climate for the Vasa ship, a circulation system that handles 90 000 m^3 /h (56) ejects fully conditioned air through twenty displacing outlets situated in an oval around the Vasa on the keel floor and also through a system for the inside of the hull that is without direct contact with the surrounding air of the museum. The interior system receives 7000 m^3/h. This figure was chosen to achieve the same ventilation of the interior of the ship as before the move into the permanent museum. The air is returned to the conditioning system through a large opening in the southeast wall of the museum hall about 25 metres above the keel floor.

In the air-conditioning system, the air is first cooled to the chosen temperature. In a second step, all or a portion of the volume of air (0-100%)is dried through cooling. The driving force for the drying process is created with the aid of a 9°C cooler and the volume of air to become processed is adjusted with an automatically operated valve reacting to the chosen relative humidity. In a final step, water is added if needed to adjust the relative humidity of the air. The air leaves the air-condition system through a 85% dust removing filter.

Two premises in the Vasa museum, namely the cinema and the exhibition area on the entrance floor, are equipped with ventilation systems (39). Each of these has a capacity of 20 000 m^3 /h. These two ventilation systems take air in common from an outside inlet and also from an inlet inside the museum. Each can get individual mixtures of internal and external air by means of manually manoeuvered valves.

The air to the two systems is not fully conditioned, but the air can be heated and cooled, humidified but not dried, separately for each of them.

The air from the cinema reaches the main museum space by a set of blowers.

Climate Control

In the permanent museum building, the climate is controlled by the settings of preferred values for RH and temperature in the ventilation system. As was stated earlier, 60% RH and 20°C were chosen for the period from June to August, and 57% RH and 17°C for the period from October to April with May and September as transition periods. The RH-setting for the October to April period has later been adjusted to 58.5%. There is also a feedback for the RH value from the computerized measuring system which uses mean values of readings from six sensors on the outside of the Vasa hull. The feedback works only on the RH control system. It warns when the RH values in the museum hall are too high or too low.

The system of different pairs of figures for the climate during different parts of the year means there are transition periods with no regulated connection with the equilibrium graph for moisture ratio in wood.

The Computerized Reading System

The sensors for measuring temperature and relative humidity both transform the measured values to electrical signals. The measuring range for the RH sensor is from zero to 100% RH. The sensor works only in surroundings with no condensation. The time constant is 60 seconds depending on the air circulation. The accuracy is ± 3% in the range from 15 to 80% RH and ± 5% in the range between 80 and 95% RH. The temperature sensor works in the temperature range between zero and 40°C. The accuracy at 25°C is ± 0,4°C. The time constant is 4 minutes and, as for the RH sensor, it is dependent on proper air circulation. The recording sensors are connected with sub-units of the central control computer of the Vasa museum.

Six of the pairs of sensors that take the signals for recording the RH and temperature are mounted inside the hull in each of the separate deck compartments. Twelve pairs are mounted on the outside of the hull at the fore and aft ends on the starboard and port sides at three levels with the three pairs placed vertically at the same lengthwise position. The choice of position for the sensors has been made using the information from a computer simulation climatic scenario as a guide. Two pairs are located on the stern and one pair in the beakhead making a total of twenty-one pairs.

The sensors are mounted in pairs with one temperature sensor and one RH sensor as a unit. That which differs from a standard mounting is the very long cable that goes from each of the sensors mounted at a particular place on the Vasa ship approximately twenty metres above the keel to the central unit in the hold of the ship. The cables to all of the sensors are long but not equally long. This caused some apprehension that the electrical signal might be affected, but the fact that the main cable has two separate cables (a twisted pair) for each of the sensors equalizes the situation for the separate sensors and also against the standard mounting situation.

To calibrate the sensors, one pair was chosen as calibration unit. The RH sensor of this unit was calibrated in a specially prepared climate chamber with between 57.7 and 57.9% RH at 20 to 25°C. The temperature sensor was calibrated against a certified thermometer. The first calibration was performed in July 1991 and it has been repeated once every year. At the first calibration, it was found that all but two of the temperature sensors were reading too low values while the opposite applied to the moisture sensors. Moreover, the discrepancy for the temperature sensors was within the specification for only 25% of the sensors while nearly 50% of the moisture sensors conformed to the specification.

Monitoring the Climate

Thermohygrograph Readings

During the period from 1962 to 1992, thermohygrographs have been used to record the temperature and relative humidity. From 1962 to 1970, this was done only around the upper parts of the hull where five thermohygrographs were placed at the level of the lower visitors' gallery and higher up in the pontoon superstructure. In 1968, one thermohygrograph was placed on the pontoon at the fore end of the hull to cover the lower parts of the hull. After the spraying had been stopped in 1979, the drying process was to be controlled only by handling the climate. It then became necessary to monitor the climate also inside the hull.

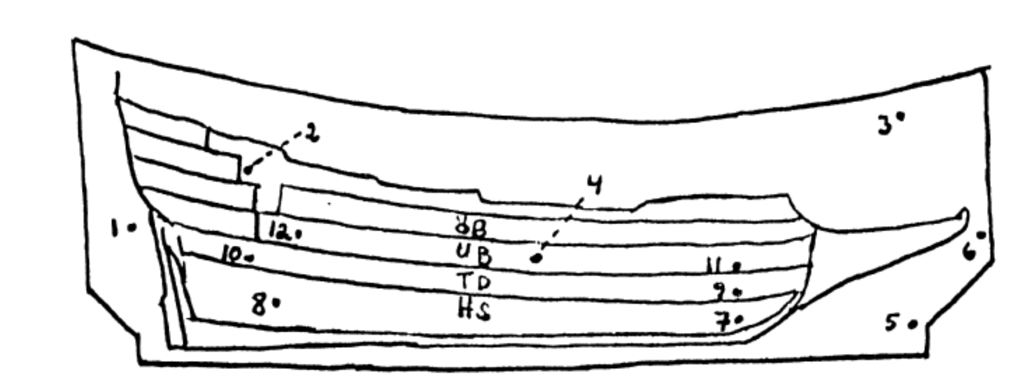

Figure 5-1 Location of Thermohygrographs inside the Vasa Hull and in the Pontoon Superstructure, longitudinal view

As no automatic spraying was then in operation, it was possible to measure the climatic parameters on board the Vasa with thermohygraphs. In July 1979, five more were placed on board the Vasa, two of them fore and aft in the hold, two fore and aft on the orlop deck and one on the lower gundeck. Because of the condensation problems that had been identified after the spray treatment had been stopped, the homogeneity of the climate of the pontoon superstructure was questioned. To check more accurately on this, the number of thermohygrographs for recording the climate around the hull was increased by four in January 1980. The new thermohygrographs were placed in the aft region of the Vasa hull. To investigate possible differences of the climate of the starboard and the port sides of the hull, two of the instruments were located on each side. One instrument on each side was placed at a level of about two metres above the pontoon and the other at the eight metre level in order also get a picture of suspected vertical gradients of relative humidity and temperature (figures 5-1 and 5-2).

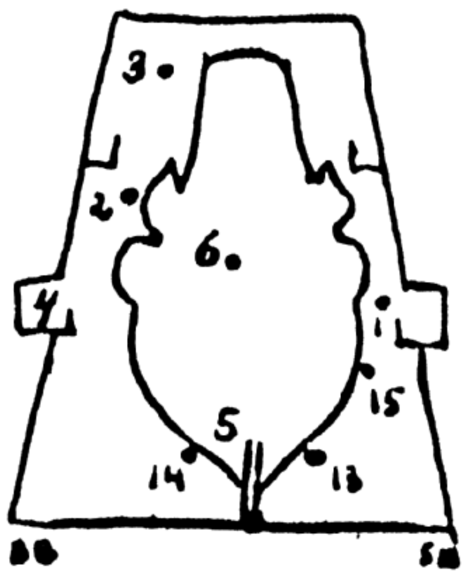

Figure 5-2 Location of Thermohygrographs inside the Vasa Hull and in the Pontoon Superstructure, transverse view

The climatic parameters were recorded on a weekly basis. The thermohygrograph diagrams have been evaluated by determining the mean values for temperature and relative humidity for each week. The grand means of the weekly values from all thermohygrographs representing the same climatic zone inside or in the surroundings close to the hull were then calculated for the separate climatic zones. Finally, the mean values for each month were calculated from the weekly values (figures 5-4 through 5-13).

The tables representing monthly mean values of temperature and relative humidity against time have been used to construct diagrams showing the overall trends of temperature and relative humidity for each climatic zone during the whole of the period for which measurements have been made. The trend diagrams are constructed as the levels halfway between the extremes for summer and winter periods. The final evaluation of the climate that has been recorded around and inside the Vasa hull has been based on the trend diagrams.

Recording Relative Humidity and Temperature with a Hand-Held Instrument

The aim when constructing the transportation encasement for the Vasa hull was to create the same climatic situation for the hull inside this encasement as had been present in the pontoon superstructure. However, the space around the hull was narrower in the encasement than in the pontoon superstructure. This might affect the air circulation picture, and this might in turn mean that the steam air-conditioning system would create RH-levels differing from those in the pontoon superstructure. The smaller space of the encasement might also affect the temperature level.

The situation called for a more extensive monitoring than could be performed with the thermohygrographs. For this purpose, six vertical positions were defined on each of the sides of the Vasa hull. At each chosen position, eight levels were defined. Three of these were low and close to the wooden surfaces while the others consisted of a vertical line at the side of the hull with measuring levels at heights of half a metre, two, three and a half, seven and nine metres (figure 5-3).

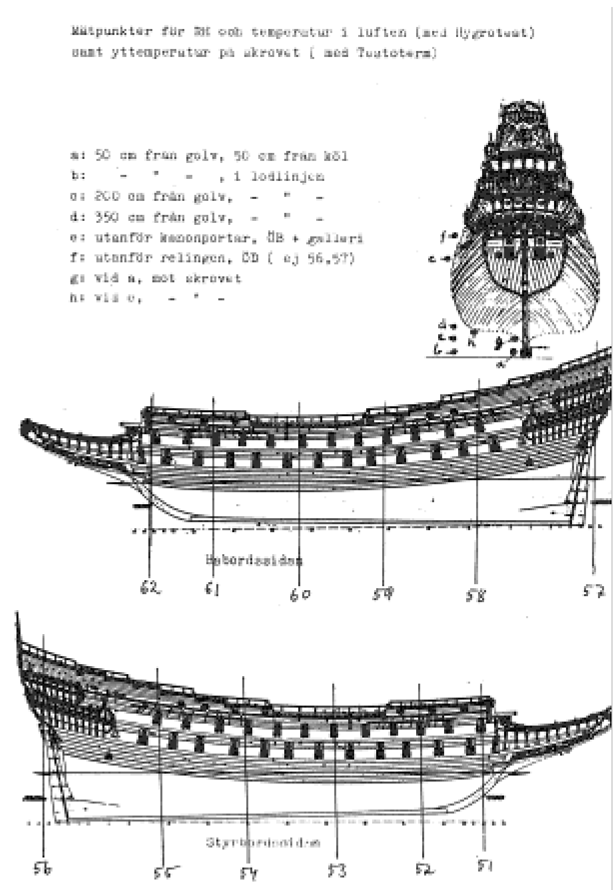

Figure 5-3 Location of points for measuring relative humidity and temperature with a hand-held meter (Hygrotest 6200)

The total number of measurement points thus amounted to ninty-six. At each defined measurement point, the temperature and relative humidity were recorded with the aid of a hand-held instrument. This type of instrument using a capacitive chromium film element for measuring relative humidity combined with a sensor for temperature readings had newly come onto the market (55).

With this easy-to-handle instrument, the temperature and relative humidity were measured and recorded about once a week from October 1988 to December 1992. Thereafter the computerized reading system had been properly tuned to take over the recordings.

Monitoring by Weighing Selected Specimens

After the six ventilation ducts had been extended from the hold to the orlop deck compartment in the autumn of 1975, the question of monitoring the result to know what had been achieved by this measure arose. To do this, four Vasa finds that had been preserved in a tank treatment mainly with PEG 4000 and climatized for a period of about two years were placed on the orlop deck so that they were not sprayed by the automatic spray system. Core samples were taken from each of the specimens and analysed for water and PEG content. The specimens were then weighed once a week. Any change in the weight was assumed to be due to a loss or gain of water and was used to calculate the current moisture ratio.

To begin with, the specimens were more or less in equilibrium with the climate in the store room where they had been kept. This meant that they had moisture ratios of between 22 and 12 per cent at the time when they were placed on the orlop deck. At the end of 1976, the specimens had reached moisture ratios between 30 and 50%. The lower values were associated with less degraded wood and low PEG ratios and the higher values were associated with more degraded wood and high PEG ratios.

This monitoring was suspended for the rest of the spray period. After the spraying had been stopped, the weighing of the four specimens was restarted at the end of 1981. The moisture ratios of the four specimens were then a little above 20%. The overall picture is that this situation prevailed during the years after 1981 until the beginning of 1986 when the drying accelerated so that rather low moisture ratios of about 10% were recorded from June to October 1986. In November of that year, the drying was arrested and reversed so that the moisture ratio stayed at a level of about 15% during the remainder of the period in the pontoon superstructure.

The next time that there was a drop in the equilibrium moisture ratio was during the summer period of 1989 when the Vasa ship was on show in the half-finished museum building. The then established equilibrium moisture ratio of about 11.5 ± 1.0% was maintained through 1990. It was followed by a level of 9.5 ± 1.0% during 1991 and 1992.

The Climatic Scenario 1962 - 1992

Around the Upper Parts of the Hull

The overall impression of the temperature development in the atmosphere of the upper parts of the pontoon superstructure is a trend of rising temperature (figure 5-4). The trend as it is defined in this work starts at 11.5°C in 1962. After having gradually climbed during a couple of years it reached a level of 13°C in 1965. The mean temperature remained at this level until 1970. From the beginning of 1970, the temperature again increased for some years until a level of 16°C was reached in 1974. In 1979 and 1980 there was again a rise in the temperature level to 17°C, which persisted during the remainder of the period in the pontoon superstructure. The rather sudden rise in temperature when the transportation encasement was constructed relates to a rise in both mean winter and summer temperatures during 1988 and 1989.

Considering the monthly mean values that were used for the construction of the trend curve the differences between summer and winter months amount to about 15°C. During the period until 1975, the winter values stayed between 5 and 8°C and the summer values between 20 and 25°C. During the remaining period in the pontoon superstructure, the winter temperatures seldom dropped below 10°C and the summer temperatures were often higher than 25°C.

From 1990 to 1992 when the Vasa had been moved to the permanent museum, the temperature level in the vicinity of the upper parts of the ship stayed at 20°C with the two extremes at a distance of about 2.5°C on each side of this level.

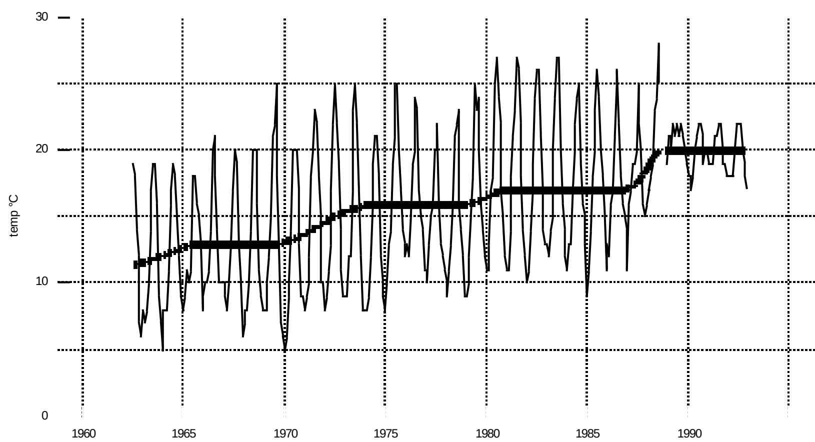

Figure 5-4 Recorded temperatures and trend around the upper parts of the hull 1962 - 1992, monthly mean values

After two stable periods at 95 and 92 % during the periods from 1962 to 1965 and from 1967 to 1969 respectively, the relative humidity showed a declining trend with a few stable periods (figure 5-5). During 1972, the RH stayed at 87%. Thereafter, the relative humidity declined at a steady rate until 1978 when there was a standstill at the 71% level until 1982. This was again followed by a period of decline at a rather even rate until 1987 when a level of 64%

RH was established during the terminating period in the pontoon superstructure and in the transportation encasement.

As with the temperature, the RH showed substantial differences between the summer and winter monthly mean values. During the period in the pontoon superstructure, this difference amounted in some cases to nearly 15 units.

After the move to the permanent Vasa museum, the RH again started to decline. It finally came to a standstill at a level of 58% at the beginning of 1991. The differences between the summer and winter monthly mean values decreased to between three and four units.

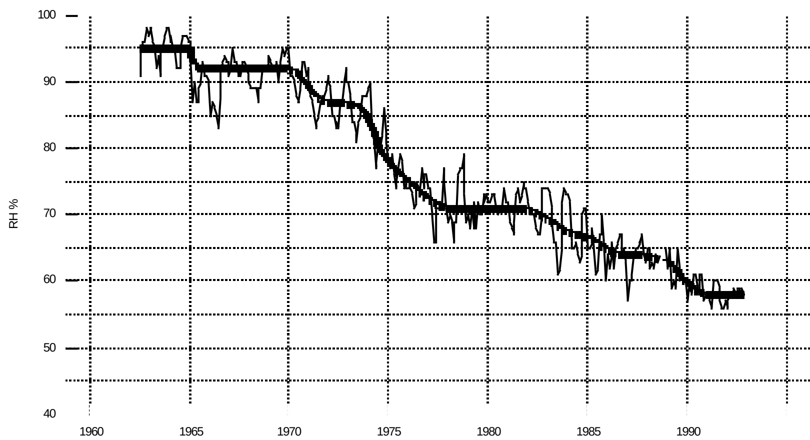

Figure 5-5 Recorded RH values and trend around the upper parts of the hull 1962 - 1992, monthly mean values

Around the Lower Parts of the Hull

The overall climate in the lower parts of the pontoon superstructure has been more stable than the climate in the upper parts. The temperature remained at 16°C from 1968 when the recording started in that zone until the end of 1978 (figure 5-6). From 1979 to 1982, the mean temperature rose one degree to 17°C. This level was maintained for the remainder of the period in the pontoon superstructure. The construction of the transportation encasement led to an elevation of the monthly summer and winter temperatures during 1988 and 1989 and as a result of this there was also an upward trend. This mean temperature level of 18.5°C was maintained during the two years from 1990 to 1992 in the permanent museum.

The differences between the monthly mean temperature values were also of the substantial magnitude of about 15°C in the lower parts of the pontoon superstructure. In the permanent museum those differences were reduced to about 6°C.

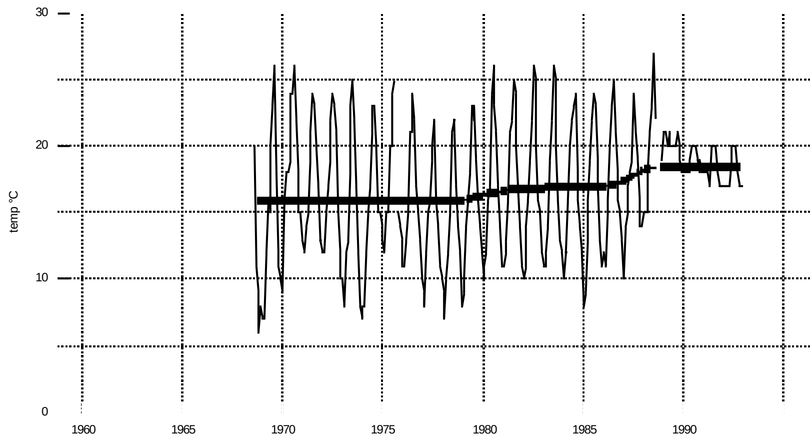

Figure 5-6 Recorded temperatures and trend around the lower parts of the hull 1968 - 1992, monthly mean values

The mean RH declined rather sharply from 94% when the recording started in August 1968 to 84% at the beginning of 1971 (figure 5-7). There was then a standstill at that level for two years. The next period of decline lasted until the middle of 1977 when there was a brief arrest of the trend at 75% RH. This was followed by a decline at a slower rate until a level of 74% was reached at the beginning of 1981. The rate of decline was then again faster until there was a standstill at about 69% RH for about a year from August 1984 until August 1985. At the beginning of 1987, the 66% RH level was reached. This level was maintained for the remainder of the time in the pontoon superstructure. The move into the permanent museum meant that there was an immediate drop in the mean RH to 63%. The level then slowly declined until a standstill at 61% was established in the middle of 1991.

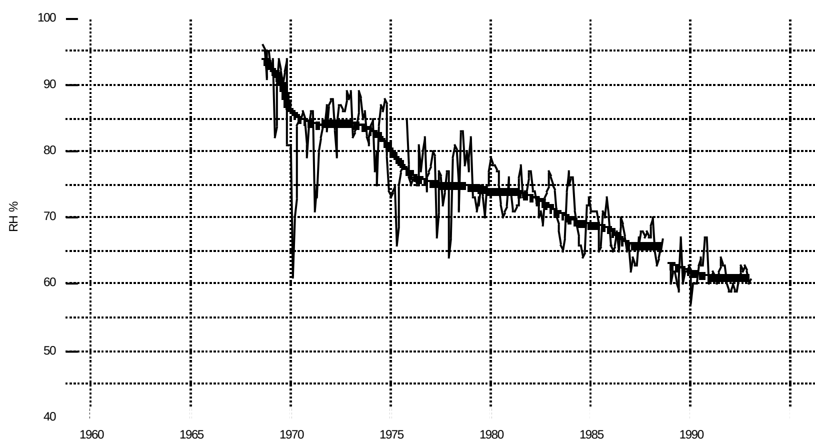

Figure 5-7 Recorded RH values and trend around the lower parts of the hull 1968 - 1992, monthly mean values

The differences between the summer and winter monthly RH mean values seem to have exceeded 15 units more often in the lower than in the higher zones of the pontoon superstructure. This tendency was also noted in the permanent museum where these differences amounted to from ten to about six units during the two years from the opening of the museum in June 1990 to the end of the thermohygrograph recordings in 1992.

Inside the Hull without Direct Contact with the Surrounding Air of the Museum

Thermohygrograph recordings have been made in the compartments of the orlop deck and the hold from July 1979 until the end of 1992. The two zones may be compared with the zone around the lower parts of the hull. As a first overall observation, the temperature levels in the hold and orlop deck remained higher than in the corresponding zone outside the hull (figures 5-8 and 5-9).

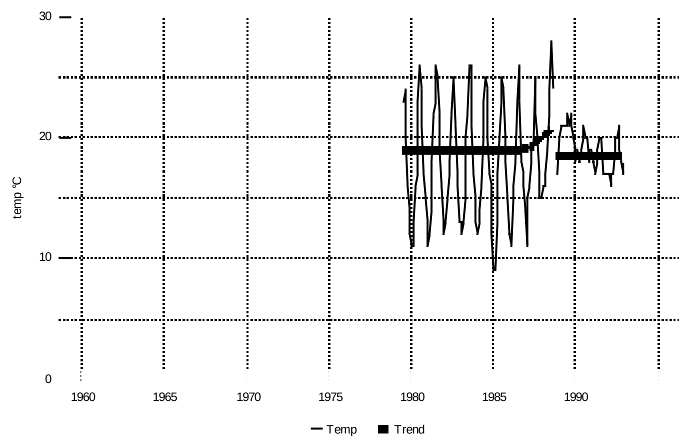

Figure 5-8 Recorded temperatures and trend in the hold 1979 - 1992, monthly mean values

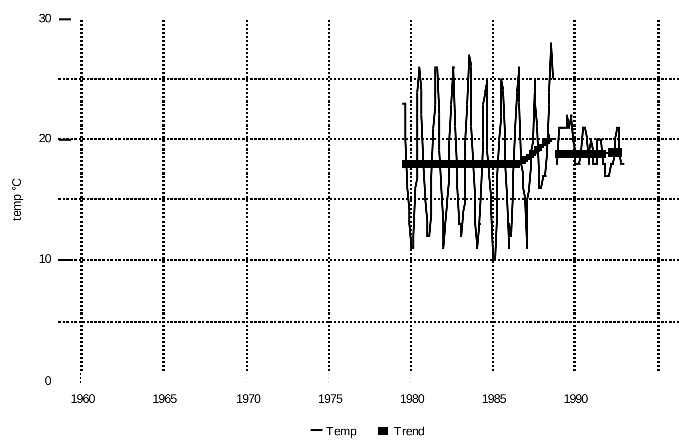

Figure 5-9 Recorded temperatures and trend on the orlop deck 1979 - 1992, monthly mean values

The same trend was observed during the whole of the period in the pontoon superstructure for each of the zones with no connection with the surrounding air. The levels were 19°C in the hold and 18°C on the orlop deck. The construction of the transportation encasement affected both zones in the same way as it affected the corresponding outside zone, i. e. with a rise in temperature. In the permanent Vasa museum, the temperature of the interior of the Vasa hull immediately dropped about 2°C, thus stabilizing at the same temperature level as the corresponding exterior zone.

If the RH trends on the orlop deck and in the hold are compared with each other, it is evident that the trend diagrams were almost identical during the period in the pontoon superstructure (figures 5-10 and 5-11). During the first three years, the level stayed at 73%. From 1983 there was a decline until the end of 1986 when a steady level of a little above 66% RH was established. This was also the final level in the pontoon superstructure for the corresponding zone outside the hull.

The first two years in the permanent Vasa museum brought the mean RH level on the orlop deck down to a level a little below 60% while the levels in the hold and on the outside parallel zone reached the same RH value of 61%.

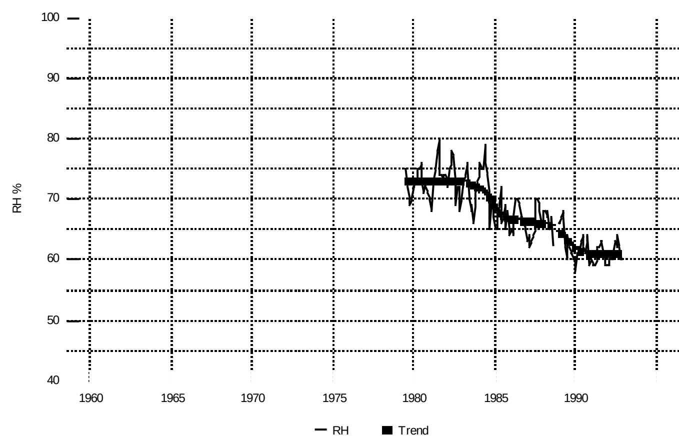

Figure 5-10 Recorded RH values and trend in the hold 1979 - 1992, monthly mean values

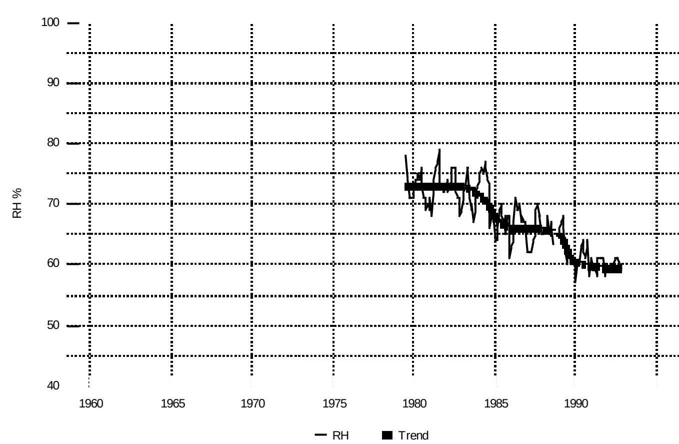

Figure 5-11 Recorded RH values and trend on the orlop deck 1979 - 1992, monthly mean values

Inside the Hull with Direct Contact with the Surrounding Air of the Museum

The temperature trend diagram for the lower gundeck resembles the diagram representing the orlop deck during the period in the pontoon superstructure. During the period in the transportation encasement, however, the level on the lower gundeck rose to two degrees above the trend on the orlop deck (figure 5-12). The level on the lower gundeck remained one degree higher than that of the parallel zone outside the hull. In the permanent Vasa museum, the temperature level of the outside zone remained 0.5°C higher than that on the lower gundeck.

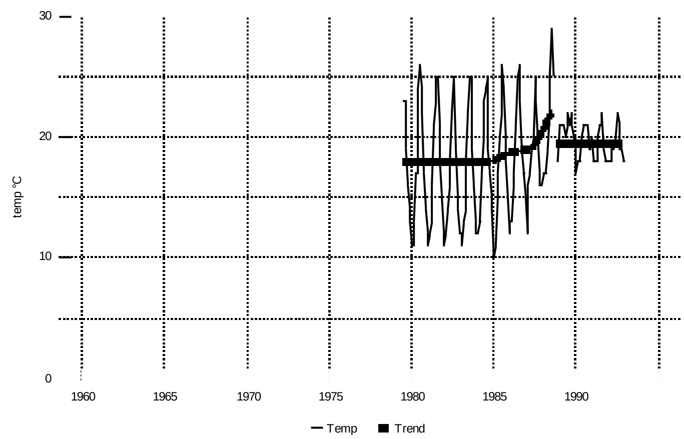

Figure 5-12 Recorded temperatures and trend on the lower gun deck 1979 - 1992, monthly mean values

Since the move into the permanent Vasa museum, thermohygrograph recordings have also been made on the upper gundeck and the upper deck. The mean temperature level on the upper gundeck stayed at 19.5°C which was the same as that on the lower gundeck. The mean level on the upper deck stayed higher by 0.5°C, which was the same as that in the zone around the upper parts of the hull.

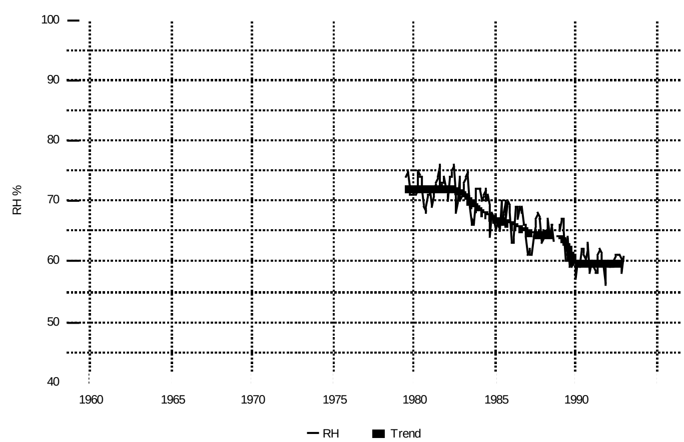

Figure 5-13 Recorded RH values and trend on the lower gun deck 1979 - 1992, monthly mean values

The RH trend diagram for the lower gundeck is almost identical with the diagram for the parallel zone outside the hull during the period in the pontoon superstructure (figure 5-13). After the move into the permanent museum, the RH level on the lower gundeck stabilized however at 60% which is about two units above the RH level of the parallel zone outside the hull. The RH levels on the upper gundeck and on the upper deck stayed at the same level of 58% as in the zone around the upper part of the Vasa ship during the first two years in the permanent museum.

An overall observation is that the move into the permanent Vasa museum was accompanied by a major change in the climatic situation compared to that in the pontoon superstructure. The temperature level of all the zones but one has risen by between one and three degrees. Only the hold shows a lower temperature trend. In that zone, the temperature level has fallen by half a degree.

As far as the RH level is concerned, the move into the permanent Vasa museum was accompanied by a drop of between 6.5 and 4.5% in all the zones where the RH has been monitored.

It should also be noted that the differences between summer and winter monthly mean values of both temperature and relative humidity have been substantially reduced.

Chapter 6

MONITORING THE CONSERVATION PROCESS

The Vasa project´s definition of conservation was confirmed through discussions at the meetings of the Conservation Council as “transforming the Vasa material from a wet unstable condition into a relatively stable condition with as little change in the material as possible”. This was to be performed by a conservation process followed by a slow drying process. It was necessary to monitor these processes in order to make decisions about how to control them.

Methods and Means of Monitoring

When Morén presented his memorandum "Dimensional stabilization of wood with polyethylene glycol" (chap. 4), Thunell put a question as to the possibility of checking the penetration of PEG. To this Morén answered that core samples had to be taken from the wood and analysed for the substance. The preservation process chosen was treatment with PEG. Therefore the monitoring was to be done by core sampling.

Core Sampling

In order that the sampling should cause the least possible damage to the wood, an increment drill was chosen to drill the cores from the wood. Further, the drill should have the smallest diameter that could produce a core from the wood of the Vasa hull. Since this could be done with a drill of the smallest diameter manufactured, this was the instrument chosen for the core sampling. Since the manufacturer changed his programme over time, the first drill used had a diameter of 3.8 mm and the ones used during the main period of core sampling had a diameter of 4.2 mm (figures 6-1 through 6-4).

Figure 6-1 Increment drill used for core sampling (photo: Sven Bengtsson)

The first sample was taken on 7 December 1962. This was a couple of months after the dimension-stabilizing treatment had started. There had been no discussion as to the size of the sample. Because the aim of the sampling was to establish the situation before the treatment, the water content of the wood was the most important feature to be established. Because of the meticulous watering programme that had been carried out (chap. 3), the water content was considered to be at its maximum level in all parts of the hull. However, the level of deterioration of the wood might be different in different parts of the hull owing to variations in environmental conditions during the burial period (chap. 3), and there might be an accompanying variation in the maximum water content of the wood. The different sizes of structural members on the other hand would have been affected similarly. Therefore, of the twelve cores that were to be analysed, six were taken from the outer planking and the other six from the inner planking. The adopted interpretation made the vertical distribution the most important. Therefore the cores from the outside planking were taken only on one side of the hull and in a vertical line from top to bottom while the horizontal distribution of the cores taken inside the hull was a question of convenience for the person who carried out the sampling.

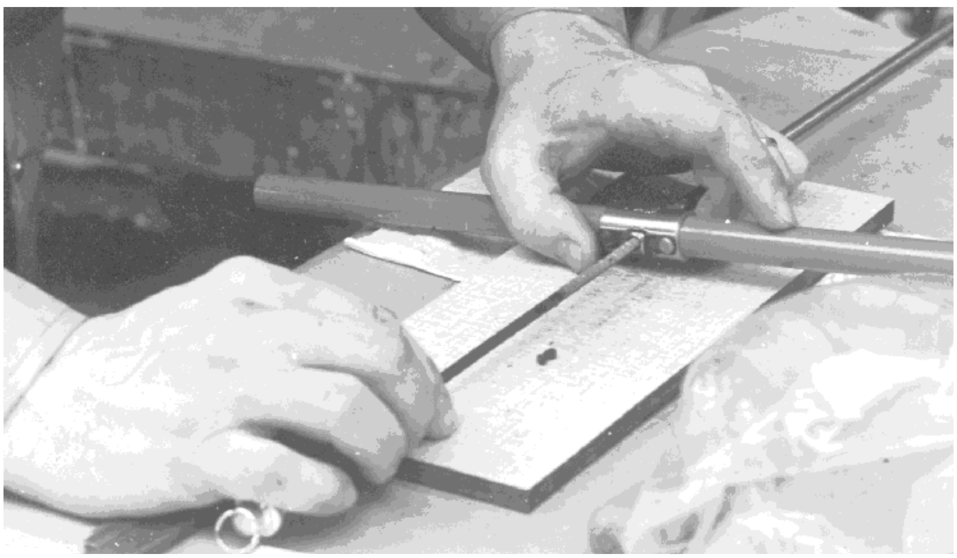

Figure 6-2 Removal of a wooden core from the increment drill (photo: Sven Bengtsson)

To obtain a picture of the situation throughout the wood, the cores were divided into pieces, each piece representing a layer at a specified depth in the wood. First a 10 mm surface layer was cut from each core. In the case of the outer and inner plankings, the rest of the core was cut into three pieces of equal length. For other categories of timber, other patterns for cutting the cores were developed. Because the members of the outer and inner plankings vary from about five to ten centimetres in thickness, the thirds of the cores after the surface layer had been removed varied in lengths from 15 to 30 mm.

Figure 6-3 Putting the 10 mm surface layer cut from a wooden core into a specimen tube (photo: Sven Bengtsson)

The cores from the heavy timbers underneath the surface layer were also cut into pieces 15 to 30 mm long. All the individual pieces were treated as separate samples during the procedure of drilling out the cores. The diagram for cutting the individual cores that was developed the first time a particular category of timber was added to the core sampling programme was repeated for all the core samples during the whole period of monitoring the conservation process.

Figure 6-4 Cutting a wooden core from a heavy timber (photo: Sven Bengtsson)

The result of the first sampling was reported to the Conservation Council at its meeting on 21 January 1963 (89). In June, the conservation department expressed some apprehension that the drying of the outer planking was too fast (90) and the second core sample that was taken in May 1963 therefore concentrated on the outer planking. Sixteen out of a total of twenty cores were taken in the outer planking and only four were taken from the inner planking. From November 1963 until October 1971, nine major core samples were taken from the Vasa hull. Eight of these comprised 30 cores from each of the outer and inner plankings. The number 30 was chosen by the research and analysis laboratory to provide a satisfactory statistical basis. During the four year period from 1972 through 1975, fourteen samples were taken, most of them with as few cores as ten from each of the outer and inner planking. The periods between samplings were made successively longer as the preservation period changed into a period of slow drying. During the period from 1976 through 1992, core sampling was performed 15 times. These samples comprised 20 cores from each of the outer and inner plankings (figure 6-5).

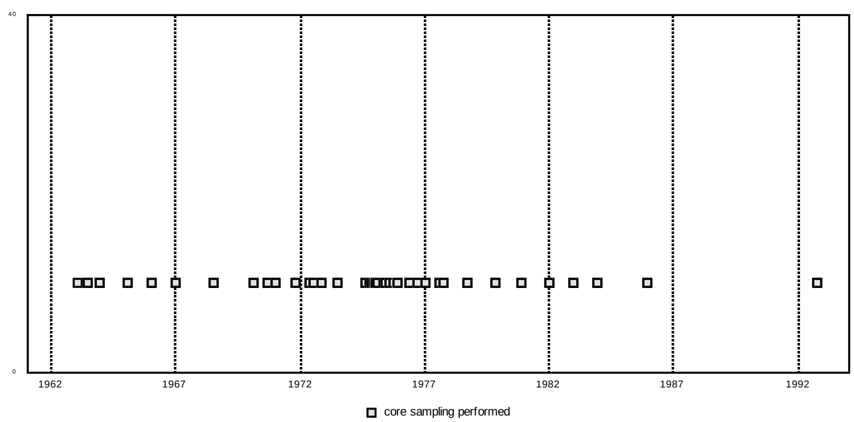

Figure 6-5 Frequency of core sampling from 1962 to 1992

Cores were also taken from members of other constructional units of the hull. From 1977, the decks were included in the regular core sampling. From about the same point in time, the wales, i.e. the heavier planks of the outer planking, and the beams and other heavy timbers inside the hull were also added to the programme.

Chemical Analysis of Core Samples

To prepare for the analysis, all the pieces of wooden cores were put into weighed specimen tubes at the site of sampling. All the core samples were analysed for their contents of water and PEG. In addition, some of the samples were analysed for their contents of boron salts and iron. The water content was determined simply by weighing the sample before and after drying. However, because of the sensitivity of PEG to temperature it was necessary to choose another way of drying than the standard procedure of drying in an oven at 102 or 105°C. The method chosen was drying at low pressure with silica gel (blue gel) as drying agent.

The methods developed earlier for the analytical determination of PEG needed rather large amounts of PEG to function and they could thus not be used for the small amounts of PEG in the small samples of the Vasa material. A method designed specially for the purpose was therefore developed by the Shell laboratories in Stockholm. The principle was that the PEG was dissolved together with other water-soluble substances by soaking the wood samples in water at room temperature. After evaporating the water, the PEG was dissolved from the residue, that had to be completely dry, by soaking in benzene for a short period of time. As there are few other water-soluble substances in archaeological wood known to dissolve in benzene, this sequence of activities separated the PEG from the rest of the substances. The final determination of the PEG in the benzene-solution was performed by determining the absorption at a wavenumber of 1107.5 cm^{-1}, which corresponds to a wavelength of 9.0 µm in the infrared region of the spectrum.

The borates used as fungicide and bactericide were also determined from the same wooden cores as the PEG. For this determination, the evaporation residue that had been soaked with benzene together with the wood core was ashed. The borates were determined in the dissolved ashes by acid-base titration.

Although this titration method is in itself rather straightforward, there were some disturbances because of the presence of sometimes large amounts of buffering salts, mostly carbonates, in the wood samples. To remove these, a portion of $Ca(NO_3)_2$ solution was added together with the NaOH solution when neutralizing the acid solution of the ash. This helped, but it was not altogether successful. The literature was therefore searched for another way of determining borates during the procedure of analysing cores from the 40th sample in 1993. As a result, a colorimetric method utilizing a complex between borate and Azomethine-H was tested with a satisfactory result. With this method, the acid solution of ashes could be used directly both for the borates and for the titration of iron. Apart from being a better analysis method for borates, this saved the three steps of neutralizing the acid solution of the ash and filtering and dissolving the precipitate.

The dissolved ashes also contain the iron that, besides the small amount that exists naturally in oakwood, was associated with iron salts from corroded iron material in the Vasa hull. Determination of the small amounts of iron was made possible through the then relatively new method of complexometric titration with EDTA. The agent used was Titriplex III (disodium salt of ethylenediamine tetracetic acid) and the analysis procedure was chosen from the standard procedures developed by the manufacturer (20).

Steps in the analysis of core samples from the Vasa material

- weighing empty specimen tubes - weight **a**

- drilling out the cores with an increment drill

- cutting the cores according to a preset diagram

- putting each piece into its separate specimen tube

- weighing specimen tubes with pieces - weight **b**

- weighing 100 ml beakers - weight **c**

- putting each piece into a separate 100 ml beaker

- putting the beakers with test pieces into a desiccator chamber with silica gel (blue gel) connected to a vacuum pump

- weighing the beakers with test pieces after the drying procedure (5 days) - weight **d**

- adding 50 ml distilled water to each beaker for soaking the test piece at room temperature (5 days)

- removing the test piece from the beaker and putting it back into its specimen tube

- evaporating the water from the solution in the beaker on a water bath

- weighing the beaker with the residue - weight **e**

- soaking the residue with benzene

- reading the absorption of the benzene solution at wavenumber 1107.5 cm^{-1} (wavelength 9.0 μm)

- reading the concentration of PEG in the benzene solution from a calibration curve for the PEG used

- calculating the weight of PEG in the test piece - weight **f**

- dissolving the rest of the residue after soaking with benzene in distilled water

- putting the aqueous solution together with the corresponding test piece into a nickel crucible

- adding 10 ml of 7.5% $Ba(OH)_2$ solution to each crucible

- drying followed by ashing at 600°C

- dissolving the ash in 10% HCl

- neutralizing the acid solution with NaOH and adding a portion of $Ca(NO_3)_2$ solution

- filtering the solution from the precipitate that contains the iron salts

- adding mannitol and performing an acid/base titration, calculating the result as boric acid - weight **g**

- dissolving the precipitate in 10% HCl

- titration of Fe with EDTA - weight **h**

Figure 6-6 Analytical programme for core samples 1962 - 1992

To calculate the final results of all the analyses, the concept of moisture ratio was chosen as a model. Because the definition of moisture ratio is water content in proportion to the dry fiber weight, it would be necessary to find the equivalent "dry fiber weight" for wood that was gradually being more and more filled with preservation substances. This ought to mean that the weight of preservatives had to be subtracted from the dry weight of each small piece of wood core. The conclusion was that to obtain any information from drying the samples, the preservatives in that particular sample must be determined. Because an equilibrium had developed at an early date between the concentration of borates in the preservation solution at a mean level corresponding to about one per cent boric acid in the wood, the borates would not add continuously to the dry fiber weight. Thus the borates could be accepted as part of the dry fiber weight and the dry fiber weight for each piece of wooden core was determined as dry weight minus weight of extracted PEG. This is a stable reference at all times for the calculation of moisture ratio as the weight of water divided by the dry fiber weight, PEG-ratio as the weight of PEG divided by the dry fiber weight, boric acid ratio, as the weight of borates calculated as boric acid divided by the dry fiber weight, and the iron ratio as the weight of iron calculated as elementary iron divided by the dry fiber weight. This way of calculation produces figures that can be used to describe the procedures over time.

Calculations

moisture ratio (%)	PEG ratio (%)	boric acid ratio (%)	Fe - ratio (%)
$\frac{((b-a)- d - c)) \times 100}{(d - c - f)}$	$\frac{f \times 100}{(d - c - f)}$	$\frac{g \times 100}{(d - c - f)}$	$\frac{h \times 100}{(d - c - f)}$

weight e = weight of the residue after evaporation of the water is used as a check on the reliability of the analyses

Figure 6-7 Formulæ for calculation of ratios (%) of water, PEG, boric acid and iron in the core samples from the Vasa

It may be noticed that the term "ratio" in this document is synonymous with "content" in the vocabulary used within the wood field.

Evaluation of the Analytical Results

The core sampling had already categorized the constructional parts of the hull as consisting of outer and inner plankings, decks and heavy timbers. In addition, the wales had been defined as a special category. The poor ventilation of the hold and orlop deck compartments might have created a different climate in these parts compared to the upper and lower gun-deck compartments situated higher up in the hull where the gunports give access to the climate outside the hull. This is the reason why the heavy timbers were divided into two categories for the discussion of conservation results.

PEG-ratios

To obtain an overview of the conservation development, a grand mean PEG-ratio has been calculated from the mean values of the PEG-ratios of all the wood cores of a sample belonging to each of the defined categories of constructional parts. In addition the mean PEG-ratios have been calculated for each level of the wood represented by a specific piece of the wooden core for each constructional category. Each mean value is accompanied by its 95% statistical confidence interval. The confidence interval is used, together with the concept that the conservation process means increasing PEG-ratios with time, to fit a trend curve to the mean values. Because the treatment programme changed rather distinctly three times during the thirty year conservation and drying period, the last one before the surface treatment period, the trend curves are broken into three parts. The curves describe the trend of the conservation development in the wood of the different constructional parts of the Vasa hull.

Comparison of the trend curves for the whole of the outer and inner plankings (figures 6-8 and 6-9) shows both similarities and differences in the shapes of the curves.

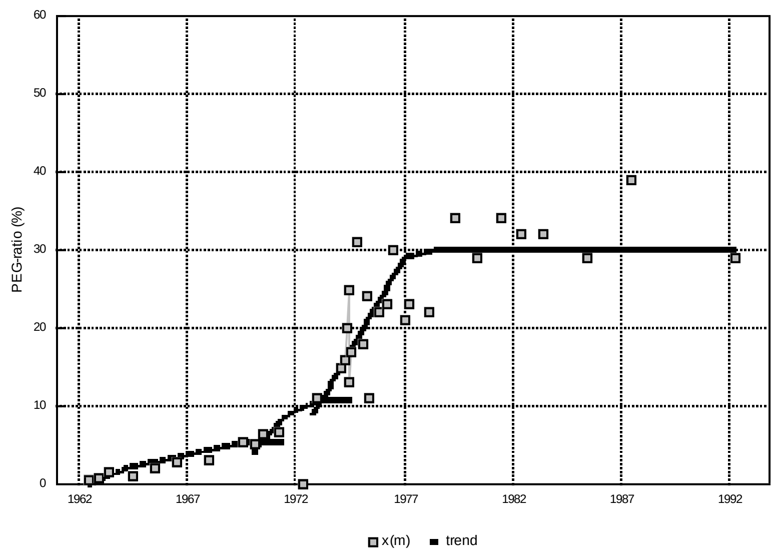

Figure 6-8 Outer planking, PEG-ratio (%) mean values and trend

During the period from 1962 until 1972, which includes the hand spraying and intensive automatic spraying periods (chap. 4), both curves show a very modest development in the degree of conservation. The PEG-ratio levels obtained were 11 and 13% respectively in the outer and inner plankings. During the next five years, when the frequency of spraying was gradually reduced at the same time as the PEG-concentration of the solution was increased, there was an increase in the PEG-ratio up to a level of 30% in the outer planking and 37% in the inner planking.

Because of the finishing surface treatment, there was an increase of PEG-ratio occasionally to mean values of 39% in the outer planking and 46% in the inner planking after the automatic spray treatment was stopped. These high mean PEG-ratios did not last because they were mainly due to a superficial PEG-coating that was applied to protect the wooden surface during the period of transportation into the permanent museum (chap. 4).

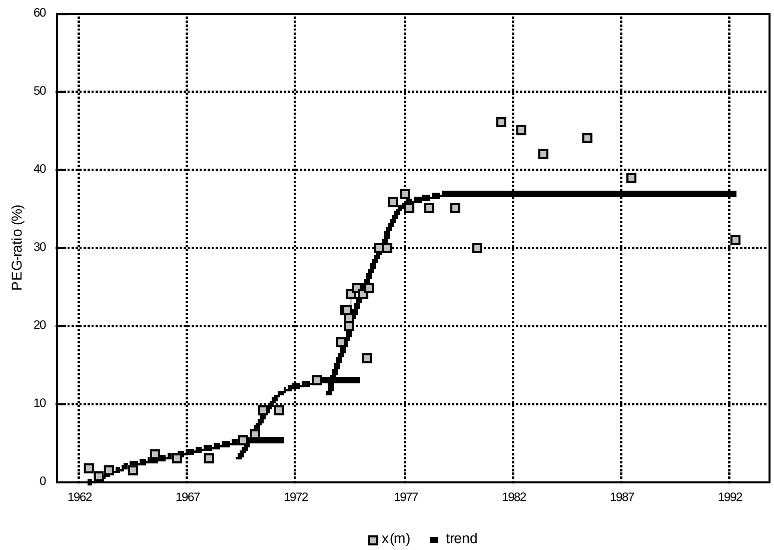

Figure 6-9 Inner planking, PEG-ratio (%), mean values and trend

From 1975, the core sampling also included the wales as a separate category. The trend curve for the mean values of the wales reached a PEG-level of about 20%. Because the wales belong to the outer planking, the trend and the mean values of PEG-ratios have been compared with the trend for the outer planking (figure 6-10).

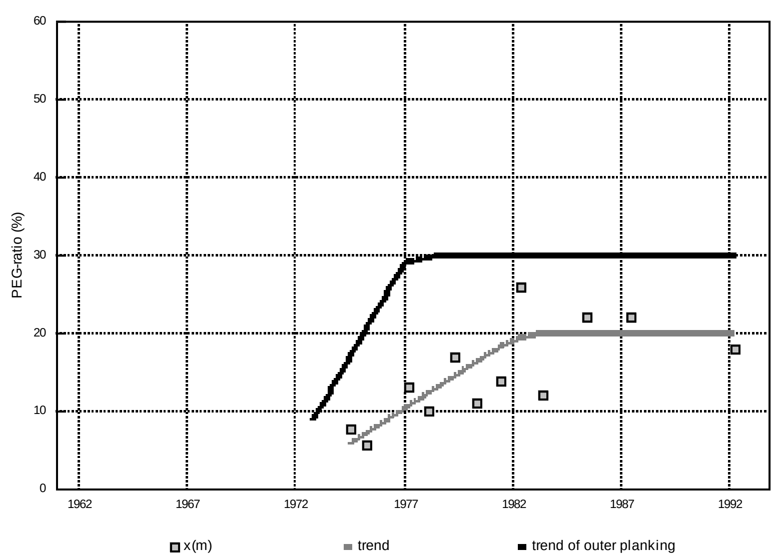

Figure 6-10 Wales, PEG-ratio (%), mean values and trend (grey) compared with the trend for the outer planking

It is noticed that, although the wales have been in the same general climate and subjected to the same treatment as the outer planking, they show lower PEG-ratios. What discriminates one from the other is the difference in thickness of the planks. The thickness of the ordinary planks of the outer planking are from 50 to at the most 100 mm, while the wales are mainly about 150 mm thick with extremes of 130 and more than 200 mm. The difference in PEG-ratios may thus be due to the fact that the planks of the wales are thicker than the ordinary outer planking.

In the same way, the PEG-ratios of the heavy timbers have been compared to the trend curve of the outer planking. In 1975, when the core sampling of the heavy timbers started, the mean PEG-ratio was as low as about 5%. Between 1975 and 1979, the timbers that belong to the spaces inside the hull that are in contact with the surrounding atmosphere of the museum building showed an increase of mean PEG-ratio to a steady level of 11% (figure 6-11).

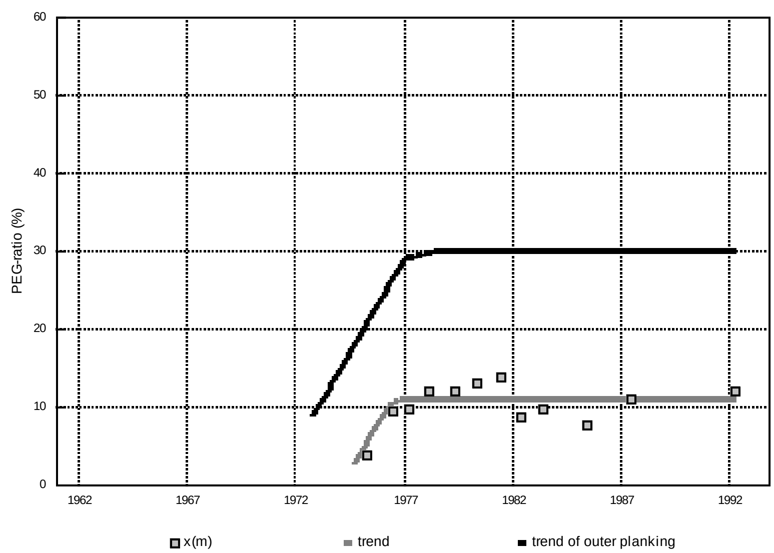

Figure 6-11 Heavy timbers in spaces in direct contact with the surrounding air of the museum, PEG-ratio (%), mean values and trend (grey) compared with the trend for the outer planking

The heavy timbers in the hold and orlop deck compartments that were not in direct contact with the surrounding museum atmosphere showed about the same increase in mean PEG-ratio during the period of automatic spraying as the heavy timbers in the spaces with direct contact with the surrounding museum atmosphere. In these parts, the PEG-level reached was one percentage unit lower than in the spaces with direct contact with the surrounding air of the museum (figure 6-12).

The rather low PEG-ratio levels of the heavy timbers were not increased despite the handspraying programme between 1980 and 1986 (chap. 4).

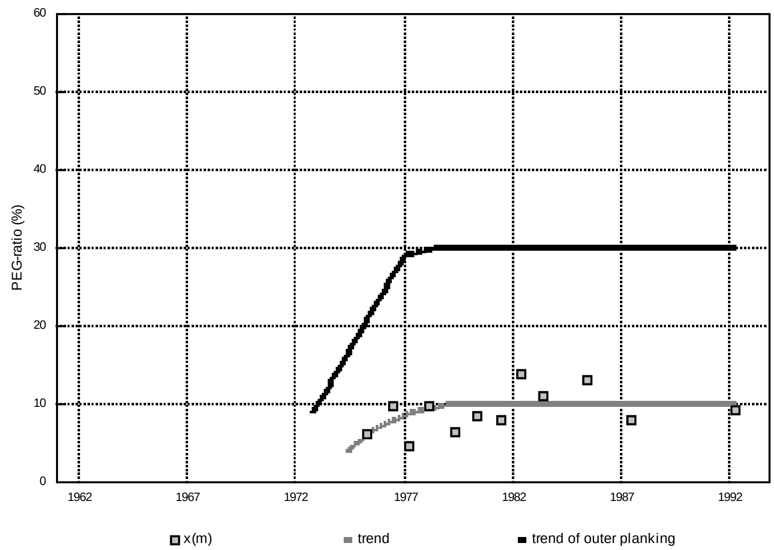

Figure 6-12 Heavy timbers in spaces without direct contact with the surrounding air of the museum, PEG-ratio (%), mean values and trend (grey) compared with the trend for the outer planking

The PEG-ratios of the upper gun-deck deckplanks fit nicely to the trend of the outer planking (figure 6-13). Although there is a considerable scatter, the final level of PEG-ratios seem to be about 30%.

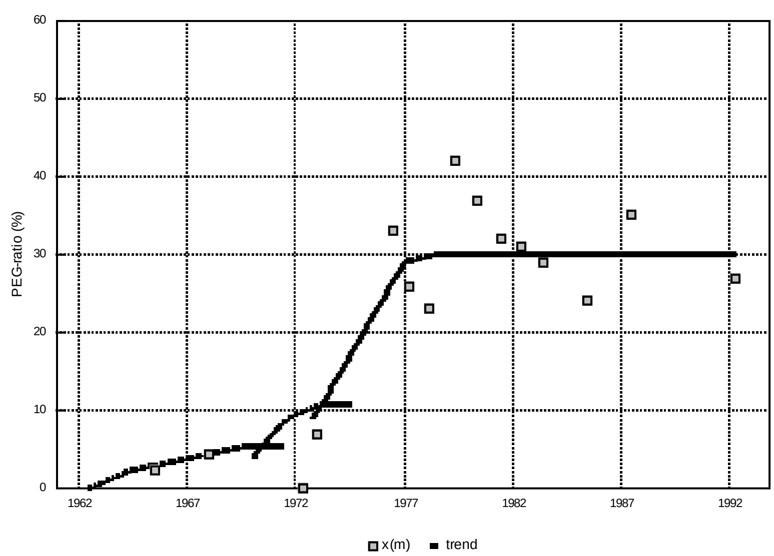

Figure 6-13 PEG-ratio (%), mean values of deckplanks of the upper gun-deck compared with the trend for the outer planking

In the case of the deckplanks of the lower gun-deck, the final PEG-ratios trend stays about six percentage units below that of the upper gun-deck, ending at a PEG-ratio level of 24% (figure 6-14).

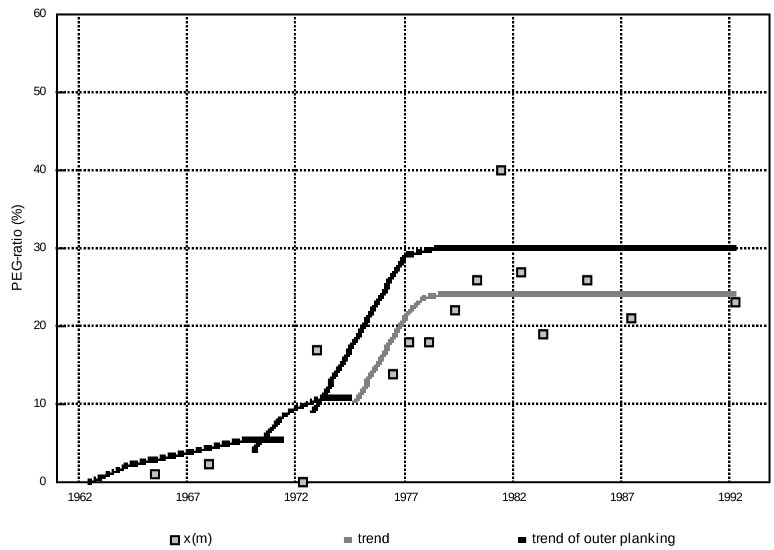

Figure 6-14 PEG-ratio (%), mean values and trend (grey) of deckplanks of the lower gun-deck compared with the trend for the outer planking

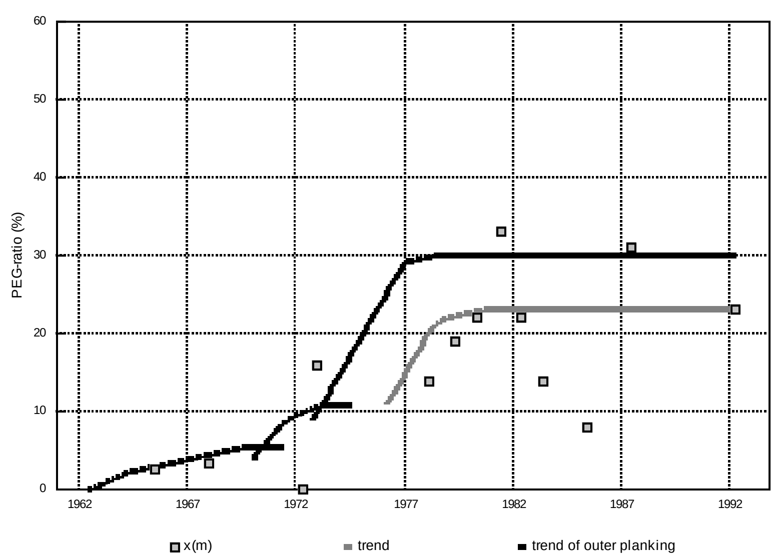

Figure 6-15 PEG-ratio (%), mean values and trend (grey) of oak deckplanks of the orlop deck compared with the trend for the outer planking

The deckplanks of the oak part of the orlop deck show a final PEG-ratio level one percentage unit lower than that of the lower gun-deck, i.e. 23% (figure 6-15). In contrast, the PEG-ratio level of the pine deckplanks of the orlop deck reach the extremely high value of 120% (figure 6-16).

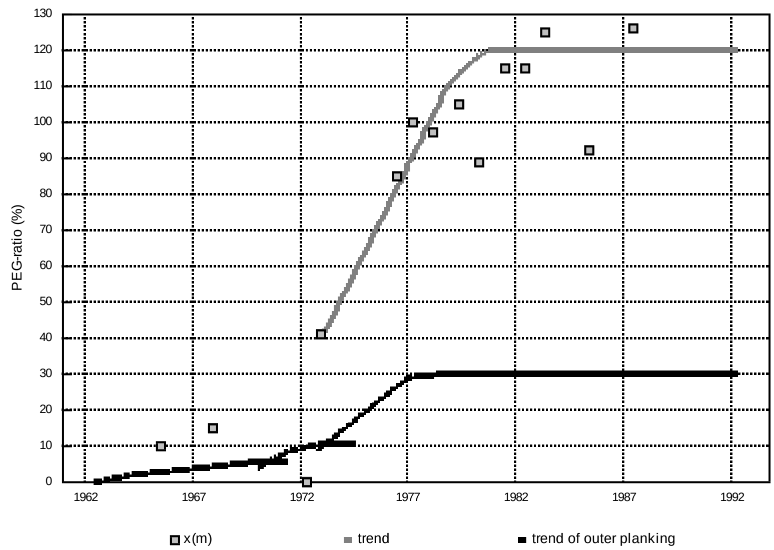

Figure 6-16 PEG-ratio (%), mean values and trend (grey) of pine deckplanks of the orlop deck compared with the trend for the outer planking

Two reasons for the differences in PEG uptake of wooden objects have been identified. It has been confirmed, as was indicated with the test panels in 1963, that variations in the climatic situation, particularly the RH-level but also the air circulation, influence the PEG uptake. Moreover, the size of the wooden object is of great importance, as has been confirmed by the example of the outer planking and the wales.

In the outer layers of each of the constructional categories, the PEG ratios reached are, however, more similar. The outer layers of the wales and of the two categories of heavy timbers may not have reached the 77 and 70% level noted for the outer and inner plankings, but they had all reached the 60% level at the point in time when the spray treatment was stopped.

Boric Acid-ratios

Because the borates were the means of controlling bacteria and fungi, nearly every core sample taken from the Vasa wood was analysed for borates, and the borates concentration in the conservation solution was adjusted when the amount of borates in the wood sank below a level of about 1% (chap. 4).

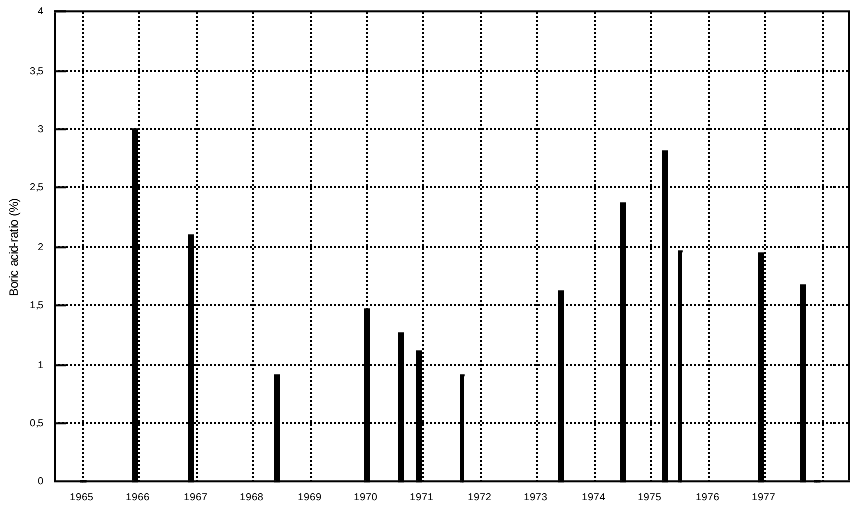

Figure 6-17 Boric acid-ratio (%) of the outer planking during the automatic spray treatment period

The boric acid ratios of the outer and inner plankings of the Vasa show similar behaviour during the spaying period. A final boric acid ratio level of above 1.5% was reached (figures 6-17 and 6-18).

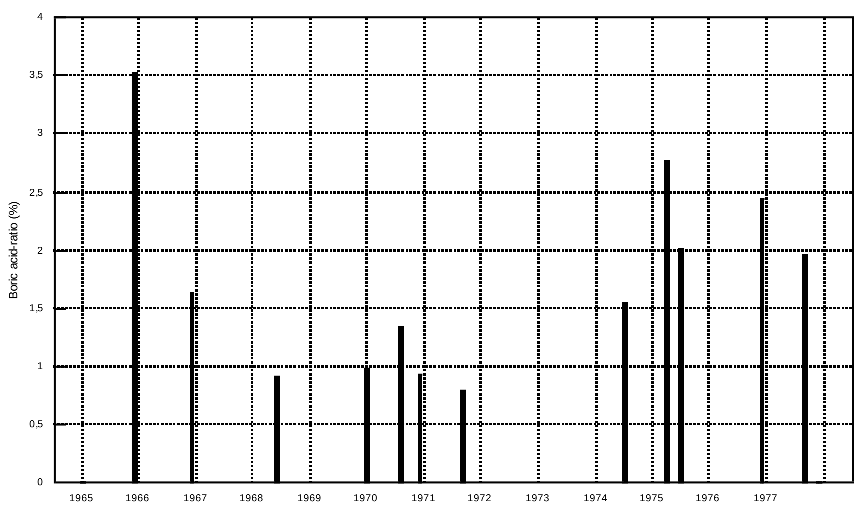

Figure 6-18 Boric acid-ratio (%) of the inner planking during the automatic spray treatment period

Iron-ratios

The timbers of the Vasa hull were held together by large iron bolts. Iron cannon balls and other items made of iron were also stored onboard the ship. During the period in the sea water, iron had slowly dissolved and leaked into the wood with an uneven distribution. Some of the dissolved iron had also reprecipitated and formed stalagtite- and stalagmite-shaped structures on the wooden surfaces. These precipitates were removed mechanically but there was no way of getting rid of the iron inside the wood.

To achieve a documentation of the iron situation, some of the core samples were analysed for iron content. This revealed iron ratios from below 0.1 to 1.5% inside the Vasa oak wood (figure 6-6).

Discussion of the Analytical Results

It was expected that the core samples would provide an indication of the point in time when a certain PEG-ratio was reached in the Vasa wood. The weak PEG uptake that was documented from the analyses of the core samples was therefore discussed at the meetings of the Conservation Council. At first, the idea was launched that a barrier layer had developed in the surface layer of the wood that hindered the penetration of PEG (94).

At the same time, it was suggested that the PEG-ratios from the analyses were not quite in accordance with the amount of PEG consumed by the spraying. This might be the result of leakage of PEG solution from the pontoon superstructure or decomposition of the PEG molecule, presumably by bacteria. Because the treatment of the Vasa was performed in a building that was open to the public as a museum, the aspect that possible decomposition of PEG might produce some substances that might be harmful to humans made the Vasa museum in 1970 request a determination of ethylene glycol in the conservation solution. The laboratory charged with this task was not convinced that ethylene glycol was an indication of decomposition of PEG. They suggested that the amount of acid products would be a better indicator of possible decomposition of PEG. According to the analyses, the preservation solution had a higher acidity calculated as acetic acid than a PEG reference solution. The figures were 0.32% and 0.0006% respectively. This might indicate oxidation and possible decomposition of the PEG molecule or that acid products had been dissolved from the wood of the hull. If the former were the case, a bacterial decomposition of PEG might be taking place. To follow up on this possibility, some "slime" was scraped from the surface of the hull. This was taken for analysis at the College of Forestry (96, §3). Two months later, it was stated that the "slime" had developed one species of slime-producing bacteria, two species of blue stain fungi and one yeast. All of these could grow on PEG.

Conceivable decomposition of PEG was not however judged to be of major importance. Instead, ways of leakage of PEG solution from the building were investigated to a great extent without any conclusion being reached (chap. 4). Because the analytical determination of PEG involved soaking the wood samples in water to dissolve the PEG, a discussion started as to the possibility that the PEG-molecule became bound to the wood cell wall so that it could not be dissolved from the wood. Thus the analytical determination of PEG by the method used was questioned, and a method of estimating the PEG content by comparing mean weight values per unit length of wood samples was adopted (chap. 4)

Extensive investigation into the matter over the years has not however confirmed the doubts about the validity and reliability of the PEG analyses.

Advance Drying of Removed Specimens

The practical situation also called for a means of obtaining some information about the effect of the PEG-ratio obtained in the wood on shrinkage when the wood was dried to equilibrium at the RH level intended in the permanent museum. The idea of a pilot drying project in advance was launched.

A recommendation was made by the Conservation Council in October 1969 that a plank should be removed from the Vasa hull and dried in the same way as was intended for the hull (94). This would be performed a couple of years ahead of the drying of the hull and thus serve as a guidline for that procedure. Upon this recommendation, an oakplank that was a hatch bar was chosen and removed from the orlop deck on 12 January 1970. The plank was two metres long and about 60 mm thick. The breadth was 330 mm at one end of the plank and 275 mm at the other. To monitor the dimensional changes that might occur as a result of the drying procedure, the plank was equipped with four pairs of probes for measuring shrinkage across the fibres. This meant mainly in the tangential direction of the wood. The plank was weighed and the distance between the probes at each measurement point was recorded. Four wood samples taken near to each measurement point were analysed for contents of water and PEG. The plank was subjected to accelerated drying by being placed in a sheltered situation in the museum. The RH and temperature in the neighbourhood of the plank were measured.

The length of the experimental period was about one year, from January 1970 to February 1971. The recorded RH-values stayed around 70%. The monitoring activities were weighing of the plank and measuring the distances between the four pairs of probes with a vernier caliper every two weeks (110, enclosure). From the monitoring activities, the moisture ratio and the shrinkage of the plank across the fibres were calculated.

Within about six weeks, the moisture ratio had decreased from 100 to 70%. Although this had caused a shrinkage of only 0.5%, steps were taken to check the development. To accomplish this, the plank was brushed with 30% PEG 1500 solution twice a day for the rest of the experimental period. This increased the PEG ratio at an even pace from a low mean value of 5% to 14% at the end of the period. Regardless of this increase in PEG-ratio, the shrinkage continued at the same rate as before the treatment started and reached a mean value of 7.6% at the end of the experimental period. Part of this was the result of a change in shape of the surface with the measuring probes from level to concave.

At the first discussion by the Conservation Council concerning the drying experiment, two facts were pointed out. The drying had gone faster than was planned for the Vasa hull. The PEG-ratio of the plank was rather low. The timbers of the Vasa hull would have a significantly higher PEG ratio at the point in time when the drying procedure was to be started. The Conservation Council therefore recommended that a new experiment should be performed. This should comprise two planks from the hull, of which one should be dried in accordance with the programme drawn up for the drying of the hull and the other should be kept inserted in its place in the hull. Both planks should be monitored equally (96).

After some discussion about how to perform the new experiment in order to obtain a meaningful answer from the chosen plank that was to be kept in the hull, two oak planks were removed on 6

August 1970 from corresponding situations in the starboard and port sides of the outer planking. The one that belonged to the starboard side of the outer planking was named "Plank No 1" and the one from the port side was "Plank No 2". Both planks were equipped with three pairs of measuring probes for shrinkage measurement across the grain. During six months, both planks were subjected to an intensive preservation treatment consisting of immersion in a tank with a 30% PEG 1500 solution during the daytime interrupted by cautious drying at 90% RH during the night. During the impregnation period, both planks were monitored by weighing and by measuring the distances between the probes.

When the six months´ impregnation period had come to an end, Plank No 2 was returned to the port side outer planking of the hull. Because Plank No 1 was to be subjected to advance drying, it was treated for another month in a 35% solution of equal parts of PEG 600 and PEG 1500 to arrive at the same degree of impregnation as Plank No 2, that would be included in the general spraying, would reach at the end of the experiment.

The PEG and moisture ratios were determined by core sampling before and after the impregnation period for each of the planks and in addition on five occasions distributed over the period of the drying programme for Plank No 1.

After seven month of treatment, Plank No 1 was placed in a succession of climates of declining RH, starting at a level a little above 85% for a period of one year. This was cautiously followed by six months at an RH slightly below 85%. Then the succession of 80 and 75% RH was given for another ten months, before the final climate of the experiment, 60% RH, was installed. Plank No 1 was kept in this climate for ten months.

However, because there was an anxiety not to repeat the mistake of not setting in additional treatment in the experiment started in 1970, Plank No 1 was brushed first once a week and later three times a week with a 50% PEG 1000 solution.This went on for almost the whole of the drying period and might have more than compensated for the fact that the plank was not included in the spraying of the hull with conservation solution. The experiment was considered to be completed when equilibrium was reached in the 60% RH climate. At that time, the mean PEG ratio of Plank No 1 was about 40% and the moisture ratio 25%. The total shrinkage during the experiment amounted to 1% which had developed between the moisture ratios 30 and 25%. Plank No 2 that had received the same treatment as the hull, had a moisture ratio of 70% and a PEG ratio of about 25% at the end of the experimental period. No shrinkage had occurred.

Since the previous experiment with two planks might not be applicable to the situation for the Vasa hull, the Conservation Council recommended at its meeting on 26 June 1974 (103) that some more planks should be removed from the hull and dried to equilibrium in an atmosphere of 65% RH. On this recommendation, two oak planks were removed from the outer planking on 1 August 1974. Both planks were situated in the starboard side of the outer planking at the same height as those used in the previous experiment. The planks were named "Plank No 3" and "Plank No 4". This time no treatment with PEG was made before the drying was started. Core samples were taken to establish the PEG and moisture content before the experiment was started. The planks were equipped with three pairs of probes for measuring shrinkage in the same way as those in the previous experiment. Changes were monitored by weighing and by measuring the distances between the pairs of probes that made up the shrinkage measurement points.

The two planks were placed in an atmosphere of 83% RH for a period of four months. During that period, the moisture ratio in both planks decreased from between 50 and 55% to about 40%. For the next two years, the planks were placed in an atmosphere of 66 to 68% RH. During that period they dried at an even rate. The end results were recorded in February 1977. At that time, Plank No 3 that had a mean PEG ratio of 14% had dried to a moisture ratio of 11% with an accompanying shrinkage of 4.9%. Plank No 4 that had a mean PEG ratio of 8% had dried to a moisture ratio of 10%, and the accompanying shrinkage was 5.9%.

The question to which an answer was sought was at what point in time the conservation treatment could be stopped. This question could be split into two. One was whether the degree of conservation already attained would be sufficient for an acceptable conservation result. The other was whether continued spraying would increase the degree of conservation or whether the process had stopped. To obtain answers to these two questions, the Swedish Institute for Wood Technology Research was engaged.

On 1 February 1977, two oak planks were removed from the outer planking of the Vasa. Both were taken to the Swedish Institute for Wood Technology Research for a test that was designed to provide the information desired. Because the testing material was to be consumed, the decision to perform the tests lay with the museum director. He gave his permission and decreed that the two planks were to be replaced by planks made of new oakwood.

The aim of the study was specified by the Swedish Institute for Wood Technology Research as establishing the drying process in two different climates, determining changes in breadth of the planks if any and determining further absorption if any during storage in a conservation solution of the same composition as that used for spraying the hull in February 1977. The temperature and RH values chosen were 35°C and 25% RH and 20°C and 65% RH, i.e. the climate intended for the permanent Vasa museum. Both planks were 25 cm wide and 8 cm thick. The planks differed somewhat in length, one was 1500 cm and the other 1850 cm long. Both planks were cut lengthwise into 30 mm thick slabs for the experiment. The monitoring activities involved weighing and measuring between probes, in the same way as was done in the previous experiments.

However, as no core sampling was performed, the PEG ratios were not determined and this meant that the moisture ratios, in the sense in which that term had been used at the Vasa conservation laboratory, could not be calculated. Instead the weight loss for each test slab was given as a percentage of the final weight of the slab in its particular experimental situation. This meant that the proportion of the weight loss that was in fact loss of water could not be compared with the moisure ratios from the previous experiments conducted at the Vasa conservation laboratory, nor could meaningful comparisons be made between the two experimental situations.

The results found by the Swedish Institute for Wood Technology Research were that the mean weight loss of the material that was kept at a low RH was 35% and the shrinkage was 1.6 and 3.4% for the different planks. The corresponding values for the material kept at the high RH were 20% weight loss and 0.8 and 1.5% shrinkage for the two planks. Storage in PEG solution was reported to have had no ameliorating effect. Some differences in dryness between slabs from the outer parts of the original plank and those from the inner parts were reported.

The results of all advance drying experiments were considered by the Conservation Council on 10 March 1977 (111). The experiment performed by the Swedish Institute for Wood Technology Research was reported by Thunell. The members of the Conservation Council expressed unanimously the view that the conservation situation was surprisingly good and that the Vasa material could even withstand a rather severe drying process. In the following discussion about the programme for ending the spraying period for the Vasa hull, the experts recommended a preliminary decision to stop the spray treatment at the end of December 1977. The Conservation Council also gave recommendations about the spraying programme for the rest of the year. The head of the conservation department, Barkman protested against both the recommended spraying programme and its recommended end-point. He recommended a more flexible programme with a prolonged and somewhat extended spraying programme with no fixed end point, although he expected the conservation process to come to an end in perhaps more than two years but less than eight years. The minutes of the meeting recorded that the conservation manager had put forward another programme.

The spraying was closed down in January 1979 (chap. 4).

Chapter 7

MONITORING THE DRYING PROCESS

Methods and Means of Monitoring

The question of how to monitor the drying of the wood was raised as early as at the second meeting of the Conservation Council (79) because the status of the timbers had to be established before the conservation process was started. Barkman therefore suggested that the moisture ratio of the wood should be determined. Opinions were expressed both for and against the possibility of using an electrical moisture meter for this purpose. However, the need for PEG analyses made it necessary to take core samples from the wood, and in the course of determining the amounts of PEG, the core samples had to be dried to establish the dry fibre weight (figures 7-1 and 7-2).

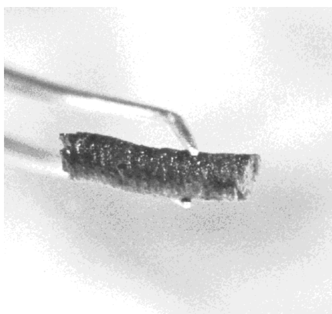

Figure 7-1 Section of a wood core being placed in a beaker for the drying procedure (photo: Björn Hedin)

The water content of the samples was thus also determined in the process of determining the PEG. From these data, the moisture ratios were calculated (chap. 6). To start with, this solved the problem of choosing a method for monitoring the drying process.

Figure 7-2 Drying the wood samples in vacuum chambers with silica gel (blue gel) (photo: Björn Hedin)

After the conservation treatment had been finished, there was less need to check the PEG content of the wood. Instead there was an interest in making more frequent checks on the drying situation. The possibility of using an electrical moisture meter was once more considered. Investigation of the market led to the choice of an instrument that could determine moisture ratios from 6 to 60 % (21). Measurements were started at the beginning of 1983 with this instrument as a complement to the core sampling.

For this, positions were designed in a system that included the lower parts of the surfaces of the outer planking that could be reached by a ladder, and the inner planking and other items inside the hull at all levels. The chosen positions were identified as measurement points with individual numbers. In order not to harm the surface of the wood by hammering the conventional pair of steel probes into the wood, a probe made of a soft rubber ring with two metal contacts was chosen. To perform the measurement, this probe was pressed firmly against the wooden surface. The moisture ratio readings were thus related to the very surface of the wood.

The moisture ratio values recorded showed good repeatability and thus seemed stable as measurement values. At first, they also agreed with the moisture ratios obtained by the analytical determination of water content in the 10 mm surface layer of the wood cores from the samples. However when the analytically determined ratios sank below a value of about 20% there ceased to be an agreement. Moreover, although the same level of moisture ratio value of 12 - 13 % had been analytically determined in two parts of the inner planking, "the upper and lower gundecks" and "the hold and orlop deck", the moisture meter values from those regions were 19 and 25% respectively. In the outer planking, there was also a difference between the analytically determined moisture ratio of 13% and the moisture meter reading of 17% (figure 7-3).

	outer planking			inner planking upper and lower gundecks			hold and orlop deck		
	m %	reading %	analysis %	m %	reading %	analysis %	m %	reading %	analysis %
1983	28	29	31	28	29	29	33	32	31
1984	27			27			34		
1985	24	24	23	23	24	21	28	27	24
1986	23			22			27		
1987	23	21	20	22	21	18	28	28	29
1988									
1989									
1990	19			19			24		
1991	18			18			24		
1992	18	17	13	19	19	12	25	25	13

Figure 7-3 Electrical moisture meter (Aqua Boy) readings , mean values per year (m) and readings taken in the same month as sampling compared with the analytically determined moisture ratio of layer I (10 mm depth) respectively for the outer planking and the two parts of the inner planking "upper and lower gundecks" and "hold and orlop deck"

A reaction between the outmost surface of the wood measured with the electrical moisture meter and the surrounding conditioned atmosphere of the museum might be the explanation of this. It might be purely a surface phenomenon or a moisture gradient in the 10 mm section of wood core that represents the surface layer.

The most significant difference between the surfaces with low readings and those with high moisture meter readings was that the former had a surface coating of PEG 4000 whereas the latter had an unprotected PEG 600 surface. The conclusion was that the difference in hygroscopicity of the PEG 4000 and PEG 600 and the difference in climatic situation between the inside and the outside of the hull were the reasons for the discrepancies in the moisture meter readings from the surface of the wood.

However, this interpretation of the result from the measurements with the electrical moisture meter called for an investigation of possible condensation on the surface of the wood. During some periods when the situation had called for instant information about the reaction of the wood surfaces, a programme for evaluating the moisture situation of the wood by systematic touching of the wood surfaces had been developed (chap. 4).

This method also became an important means of monitoring the surface of the Vasa hull during the period in the narrow transportation encasement. The same plan of selected surface areas was employed as was set up in 1981. The whole scale of notations of "dry surface", "slightly moist surface", "moist surface", "slightly wet surface" and "wet surface" was used. The investigation method was applied both during the period in transit that lasted from August 1988 until June 1990 and during a period in the permanent museum that started in September 1990. The areas were investigated about once a week.

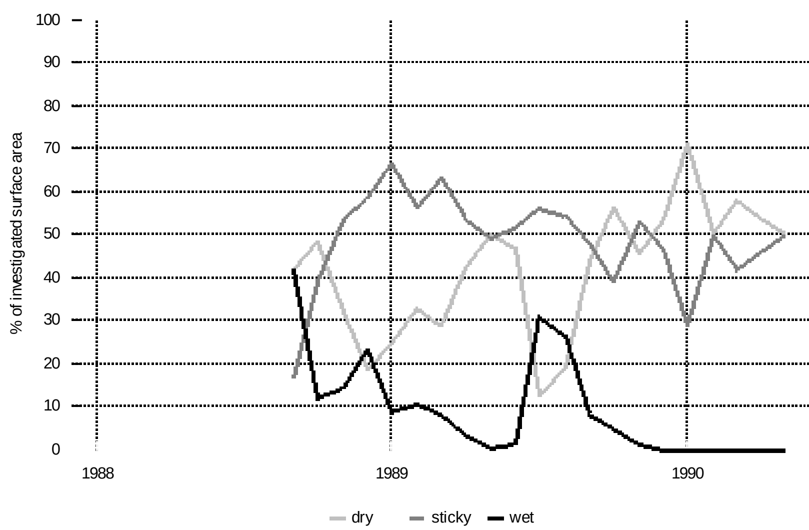

Figure 7-4 Surface investigation, August 1988 - June 1990

There was a substantial variation in the observations during the period in the transportation encasement. There even arose a need for a greater specification of the observations. During the summer of 1989, when the Vasa was exhibited to the public in the half-finished museum, and during the winter and spring periods when the transportation encasement was gradually removed, a stage between "dry" and "slightly moist" was identified. Therefore the notation "very slightly moist" was added to the list.

To obtain an overview of the situation, the notations were grouped into three categories. The one called "dry" consisted of the original "dry" notations, the one called "sticky" consisted of the three categories "moist", "slightly moist" and "very slightly moist", and the one called "wet" consisted of the original "slightly wet" and "wet" notations.

During the period in the transportation encasement, "sticky" notations were present mostly to an extent of between forty and sixty per cent while the "dry" notations varied substantially from fifteen to seventy per cent. The low percentages of "dry" notations were recorded in December 1988 when the transportation encasement was moved into the museum under construction and then when the encasement was partly removed in the summer of 1989. On these two occasions, the "wet" notations rose to levels of over twenty and thirty per cent (figure 7-4).

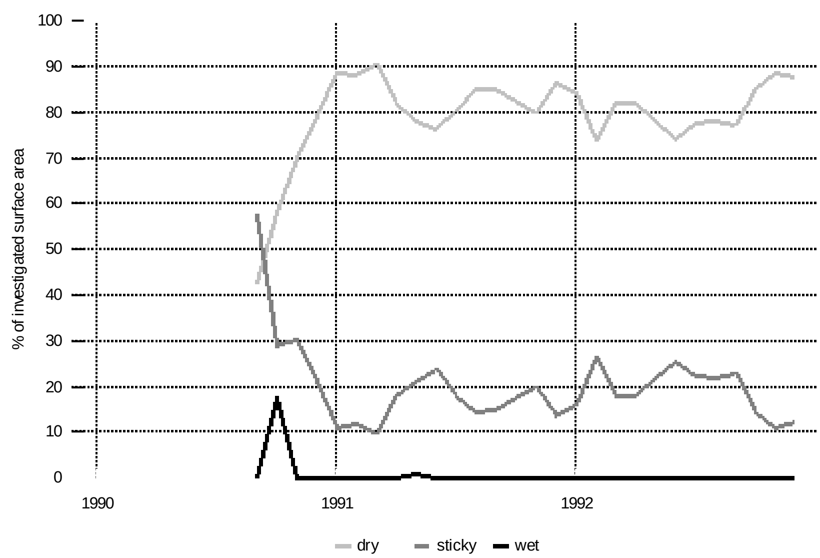

Figure 7-5 Surface investigation from September 1990 to the end of 1992

The same situation as in June existed when the monitoring of the wooden surfaces started again in September 1990. The "sticky" and "dry" notations each ranged from forty to sixty per cent. There were even some "wet" notations during the autumn of 1990. However, the climatic prerequisites seem to have stabilized during the winter period, giving ninety per cent "dry" and ten per cent "sticky" notations. During 1991 and 1992, these notations ranged between seventy-five and ninety per cent and ten and twenty-five per cent respectively. This indicates that the PEG-treated wooden surfaces react to even mild changes in the surrounding climate (figure 7-5).

Evaluation of the Analytical Moisture Ratio Data

The moisture ratios (chap. 6) have been calculated for each core section and as a mean value for each core. The mean value and the 95% level confidence interval for each sample have then been calculated and, in accordance with the concept that the drying process leads to a decrease in moisture ratio with time, a curve has been fitted to the mean values.

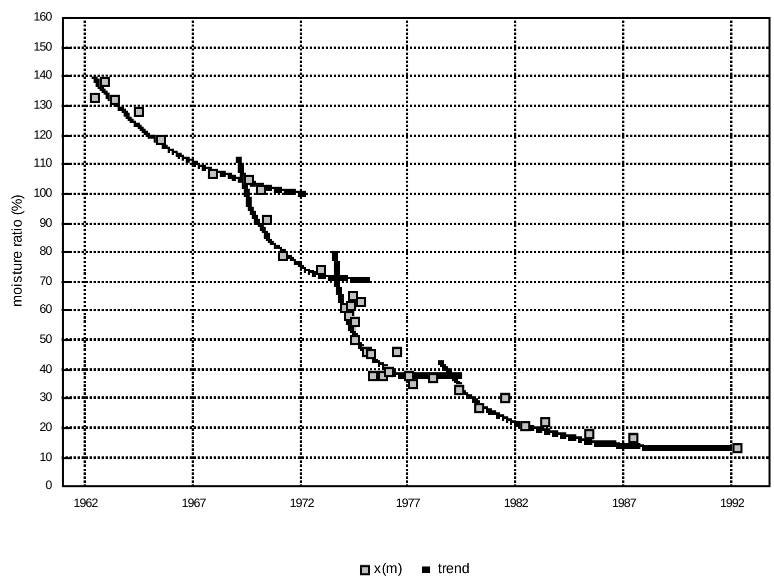

Figure7-6 Outer planking, moisture ratio (%), mean values and trend

The drying of the Vasa wood was controlled during the first period after salvage by water spraying of all surfaces. Thereafter, a continuous spraying with an aqueous PEG solution was carried out for a period of about ten years until 1972. During this period, no drying was planned. During the next six years, intervals of succesively increasing length were interposed between the sprayings. This meant that the period was a controlled drying period as well as a preservation period. After this period, the drying has been controlled by adjustment of the RH, temperature and air movement. Apart from the planned control of the drying process, the climatic parameters were different for differently situated constructional parts of the hull.

During the continuous spraying period, samples were taken for analysis only from the parts that were judged to be the most important with respect to PEG uptake. These were the outer and inner plankings. During the hand-spraying period there was a decrease in moisture ratio from a maximum mean water ratio value of 150% to about 130% for the inner and 120% for the outer planking. Although the hull was not meant to dry during the intensive spraying period, there was a further decrease in moisture ratio of about 40 percentage units at the end of the intensive automatic spraying period (figure 4-24). Two different drying-rates can be identified during this period. The moisture ratio sank slowly from about 130% to 110% in the inner planking and from about 120% to a little less than 110% in the outer planking during the period of about five years of intensive spraying with 10 and 15% PEG-solutions. During the next three years with the same frequency of spraying but with conservation solutions of 20 and 25% PEG-concentration (figure 4-12), the drying was more rapid and the moisture ratio sank to 85% in the inner planking and to a little below 80% in the outer planking (figures 7-6 and 7-7).

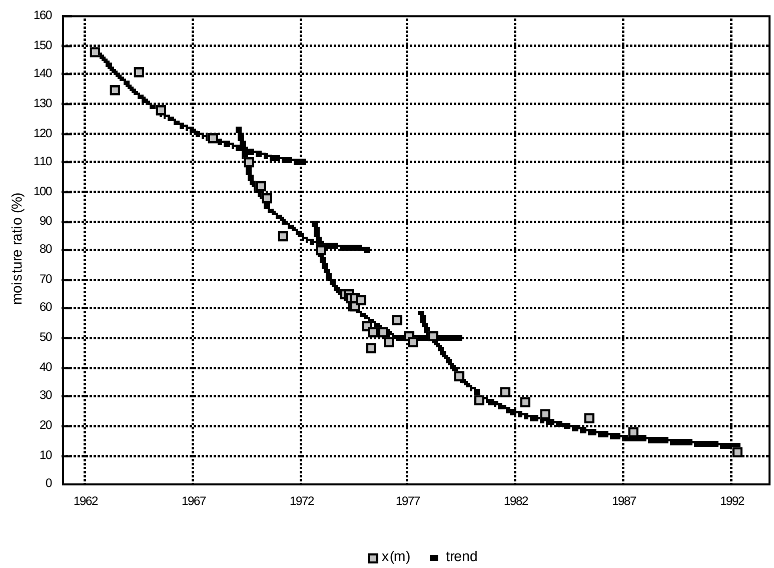

Figure 7-7 Inner planking, moisture ratio (%), mean values and trend

During the period 1973 - 1976 of intermittent spraying, the rate of drying was about the same as during the latter part of the intensive spraying. The moisture ratio levelled out at about 40% in the outer planking and 50% in the inner planking. The drying started again during the finishing surface treatment period when special measures were taken to speed up the drying and reach the end-point of the preservation period (chap. 5). A moisture ratio of about 20% had been established before moving into the permanent museum. During the first two years in the permanent museum, the drying had continued to an equilibrium with the climate in the museum at a moisture ratio of between 10 and 12% for the outer and inner plankings.

Although the outer and inner plankings had been the main target for core sampling, the situation in the heavier timbers had to be established. Therefore the core sampling programme started to involve the wales and the heavy timbers and also the decks inside the hull from about 1975. Even the ribs were investigated by core sampling a couple of times.

It was expected that the drying process might be slower in the heavy timbers. In the case of the wales, this proved not to be true. The mean moisture ratio values fit well to the trend diagram of the outer planking (figure 7-8).

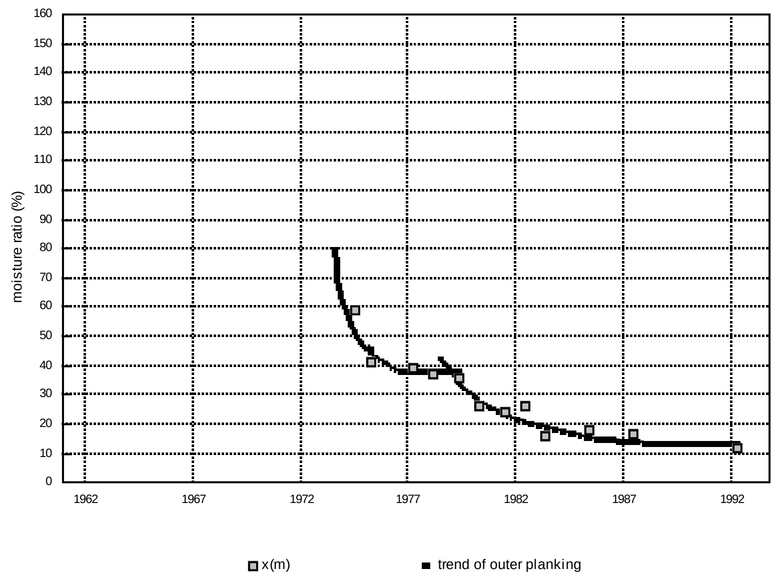

Figure 7-8 Wales, moisture ratio (%), mean values compared with the trend for the outer planking

Although a year behind in drying when the first core sample was analysed in 1975, the heavy timbers of the upper and lower gundecks had reached the same moisture ratio level as the outer planking before the spray treatment was stopped. The latter part of the drying curve fits well with the drying curve for the outer planking and the wales (figure 7-9).

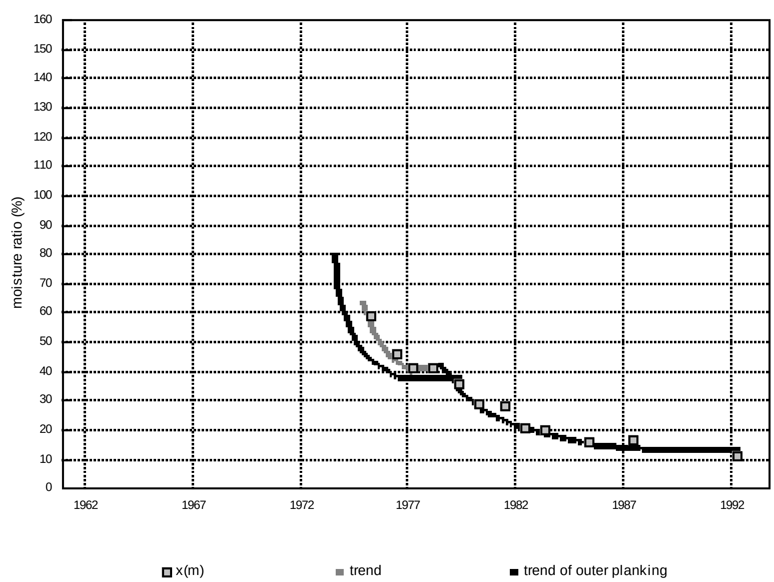

Figure 7-9 Heavy timbers in spaces in direct contact with the surrounding air of the museum, moisture ratio (%), mean values and trend (grey) compared with the trend for the outer planking

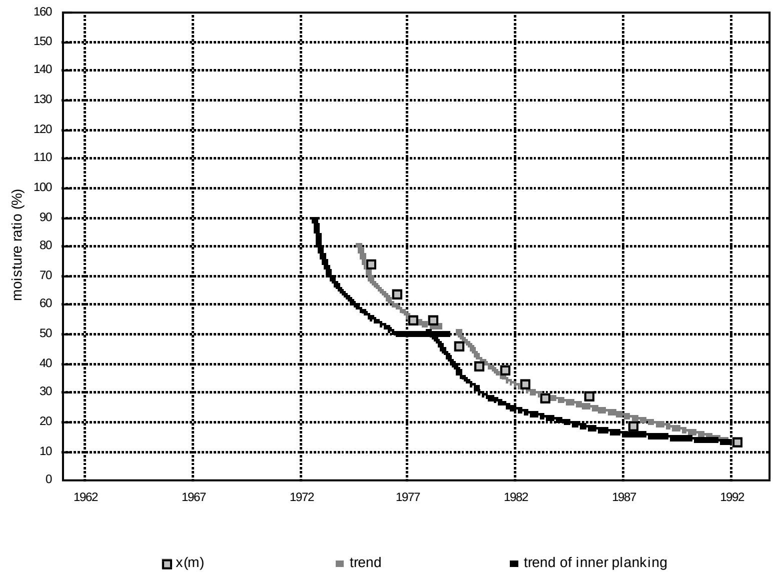

Figure 7-10 Heavy timbers in spaces without direct contact with the surrounding air of the museum, moisture ratio (%), mean values and trend (grey) compared with the trend for the inner planking

However, the heavy timbers inside the hull belonging to the hold and to the orlop deck that had no contact with the surrounding air of the museum showed a moisture ratio about ten percentage units higher than the already mentioned categories of heavy timber before the transfer to the permanent museum (figure 7-10).

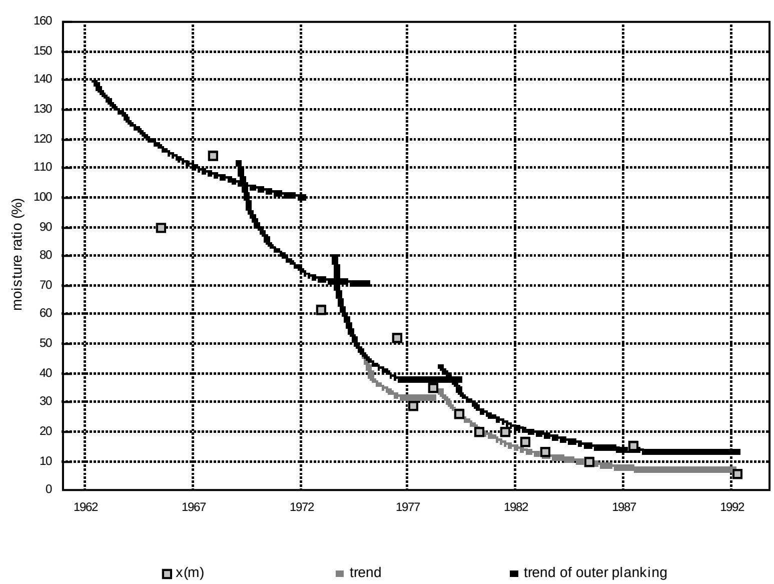

Figure 7-11 Moisture ratio (%), mean values and trend (grey) of deckplanks for the upper gun-deck compared with the trend for the outer planking

The oak deckplanks of any of the decks dried faster than the inner planking. Surprisingly they all showed similar drying curves and, they all arrived at the 20% moisture ratio level about three years earlier than the inner planking. The difference had however levelled out in 1992 after about three years in the climate of the permanent Vasa museum (figures 7-11 through 7-13).

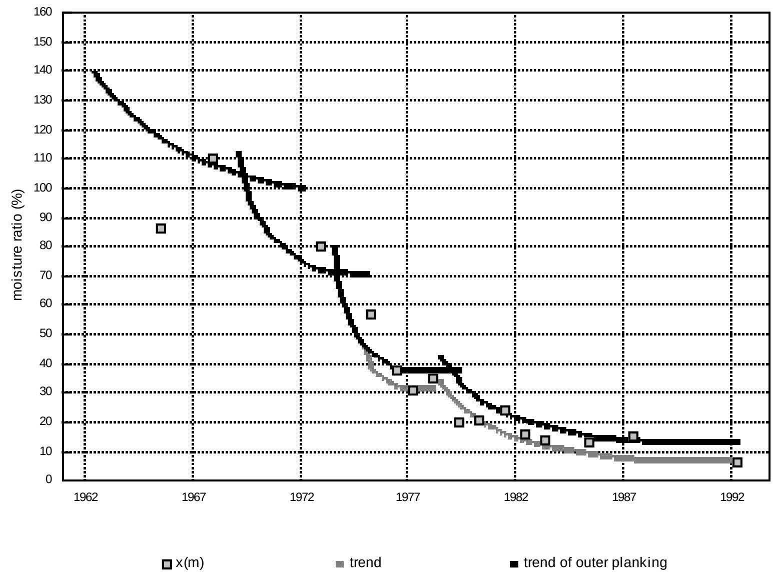

Figure 7-12 Moisture ratio (%), mean values and trend (grey) of deckplanks of the lower gun-deck compared with the trend for the outer planking

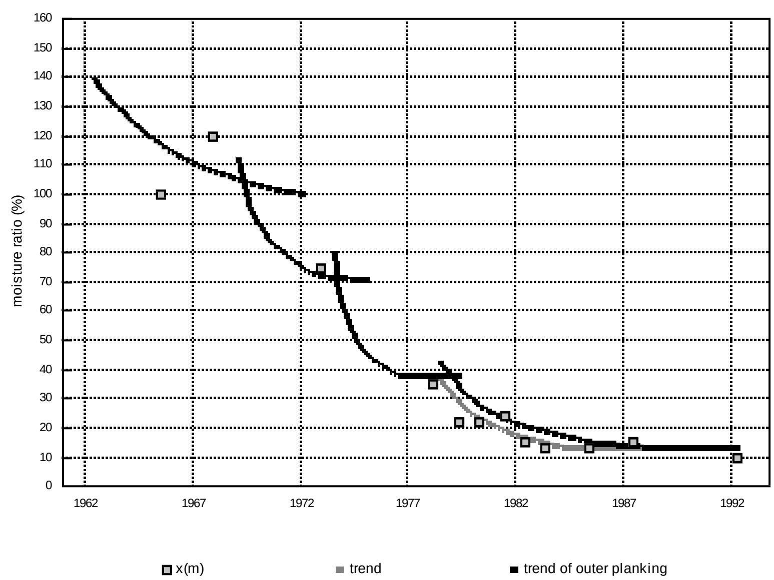

Figure 7-13 Moisture ratio (%), mean values and trend (grey) of oak deckplanks of the orlop deck compared with the trend for the outer planking

The main part of the orlop deck construction consists however of pine deckplanks. These show a quite divergent drying behaviour compared with the oak deckplanks, as was also the case with the PEG uptake (chap. 6). The constructional pinewood in the Vasa hull had a moisture ratio in the fully waterlogged state about 30 percentage units higher than the constructional oak wood. This difference remained during the preservation period. Its magnitude became however smaller when the spraying ceased and the drying period started, but even at the time when the Vasa arrived at the permanent museum, the difference was still about 15 percentage units. During the investigated three-year drying period in the permanent museum, the oak and pine materials however arrived at the same final moisture ratio of about 10% (figure 7-14).

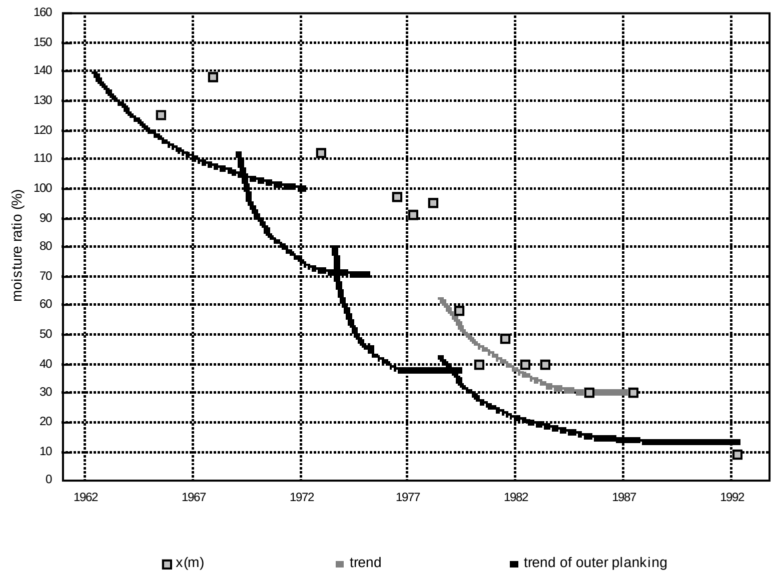

Figure 7-14 Moisture ratio (%), mean values and trend (grey) of pine deckplanks of the orlop deck compared with the trend for the outer planking

Shrinkage Measurements

The danger that the drying of the wood would be too rapid and would be accompanied by shrinkage and distortion of the timbers was judged to be the main threat when the huge Vasa hull had been salvaged. Therefore the first monitoring measure was to fit some strain-gauge equipment. To overcome the special difficulties of mounting such equipment on the waterlogged and water-sprayed Vasa hull, a special method was introduced by a consulting engineer (85), Torsten Ljungström. He mounted the strain gauges on springs that were nailed to the wood. There were two types of arrangement, depending on whether movements between separate parts or members of a construction or movements of the wood itself were to be monitored. To monitor the latter type of movement, seven strain-gauge units were placed on timbers of the outer planking and the wales. A report to the Conservation Council in January 1962 said that from 15 September 1961 when the measurements were started there had been very small movements but that there was a noticeable change when the water spraying had to be stopped on 15 December because of the risk of freezing.

The strain-gauge equipment was however sensitive to the humid climate of the pontoon superstructure and in August 1965 a more robust method of monitoring by using a vernier caliper was introduced. For this purpose twelve pairs of stainless steel probes each 50 mm long and 2.5 mm in diameter were hammered into the Vasa wood to a depth of 30 mm. The measurement distances were about 120 mm. Six of these first twelve measuring points were placed on the outer planking and two on the wales. These constructional parts were judged to have the greatest danger of drying. One measurement point was placed on the inner planking at the level of the upper gundeck and one on a member of the inner planking in the hold. Two items of heavy timbers, a knee on the lower gundeck and a beam on the orlop deck, were also included in this first series of measurement points for shrinkage monitoring.

The series of measurement points was enlarged from the middle of 1975 when the categories of heavy timbers were also included. At the most, there were sixtyseven measurement points on the timbers of the hull. Of these, twentyfive were placed on heavy timbers, eighteen on the outer planking, fifteen on the inner planking and nine on deck planks.

Since the Vasa was moved to the permanent museum, many measurement points on the outer planking have become inaccessible. However there are still thirtyseven measurement points left for monitoring shrinkage of the timbers of the Vasa hull.

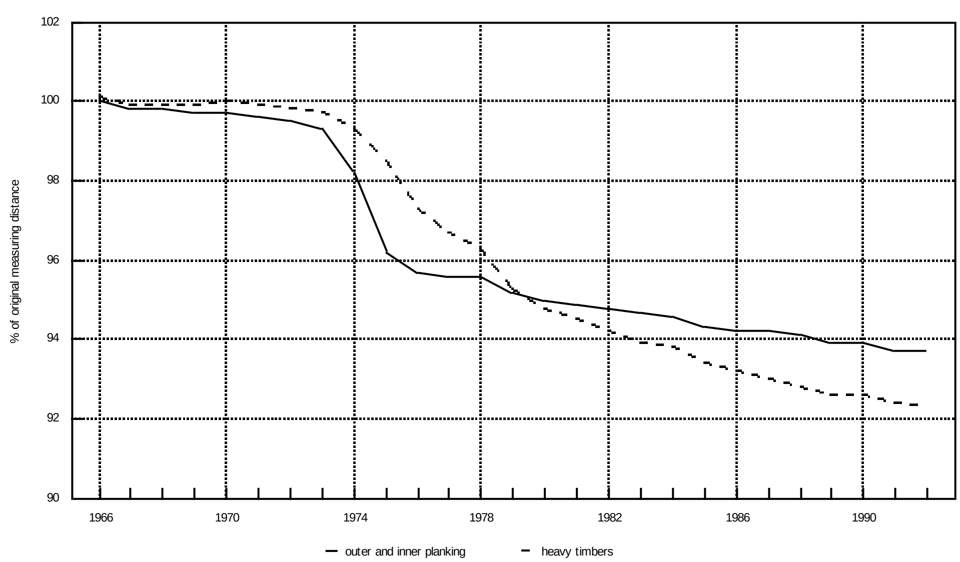

Figure 7-15 Shrinkage of outer and inner plankings (continuous line) and heavy timbers inside the Vasa hull (broken line) 1966 - 1992

Evaluation of the shrinkage measurements

To obtain comparable figures, the changes in distance between the measurement probes have been calculated as a percentage of the original distance between the same pair of probes. To provide an overview of the situation, the mean values for the outer and inner plankings have been calculated for each year and also the mean values for the heavy timbers inside the hull (figure 7-15).

From the graph, it can be deduced that there was very little shrinkage before 1973 in either thin or heavy materials although the moisture ratio dropped to about 80% during the period (figures 7-6 and 7-7). However, the next decrease in moisture ratio from 80 to about 40% was accompanied by a shrinkage of the members of the inner and outer plankings of about 4%. From a moisture ratio level of 40% down to the 1992 level of 10 to 12% there was a slow shrinkage of about 1.5%. In all, the mean total shrinkage of the outer and inner plankings has been slightly above 6%.

Throughout this period the heavy timbers have shrunk at an even rate without arriving at a standstill. In 1979, their shrinkage curve crossed the shrinkage curve of the outer and inner plankings. The mean total shrinkage of these amounted to nearly 8% at the end of 1992.

Chapter 8

VISUAL ASSESSMENT OF THE RESULTS OF THE PRESERVATION

The possibility that the timbers of the Vasa hull might develop cracks and surface checking was of great concern from the time when the hull was removed from the sea until it was safely inside the pontoon superstructure and was subjected to conservation treatment in a climate of high relative humidity. During the period of intensive conservation treatment that lasted until the end of 1972, no shrinkage or cracking was expected, and for a long time there was no change in the visual appearance of the hull. When, for the first time, the results of the shrinkage monitoring measurements were brought up on the agenda of the Conservation Council (95), the meeting observed that there was a very slight shrinkage at that time (chap. 7). Even in January 1974, after one year of diminishing intensity of the spray treatment, the shrinkage was still less than one per cent and the Conservation Council judged that it was sufficient to receive reports on the shrinkage situation once a year (102).

However, in the autumn of 1974, the engineer (Arne Stolth) in charge of the conservation treatment of the Vasa reported that the seams between the couple of wales below the row of lower gunports and the planks above and beneath those wales had widened on both the starboard and port sides in the aft part of the Vasa hull. He also reported that some minor superficial cracks had appeared.

First Systematic Inspection

Because of the reports from Arne Stolth, the conservation department decided to survey the situation in connection with the core sampling in November 1974. Bo Lundvall, who bored the cores, also made a survey from the top to the row of lower gunports on the starboard side of the hull. Starting in the fore part of the hull, he noted a very minor opening up of the seams along about one fifth of the length of the hull. Slightly more conspicuous openings were noted in the middle part of the hull and somewhat larger openings in the aft part. In the aft region on the port side of the hull there was a wide opening of the seam between the wale below the lower gunports and the planks above that wale.

However, no cracks were reported, only the opening of seams.

The "Control group for the state of conservation of the Vasa hull"

To obtain some idea of what might happen to the visual appearance of the Vasa hull as the drying process proceeded, the tank-treated Vasa material that had already been dried to a certain extent was inspected. Its visual appearance was discussed in relation to the amount of PEG absorbed and its state of dryness. Nevertheless there were different opinions as to what might happen to the hull during the drying process and whether it would affect the hull to such an extent that it would not remain an acceptable museum piece.

Because of the difference of opinion about the likelihood of the Vasa hull degenerating out of control, the museum director decided to set up a "control group for the state of conservation of the Vasa hull". To launch the group, he called a meeting of the heads and some appointed collaborators of the Conservation and Vasa departments on 15 January 1975. The duty of the group would be to continually survey the Vasa hull from the conservation point of view and to record the changes that might be expected over the years to come. The group was to be composed of the heads and collaborators of the Conservation and the Vasa departments who were called to the meeting. An additional external expert was to be appointed by the museum director in consultation with the chairman of the Conservation Council. The appointment of the control group was confirmed by the museum board at its first meeting in 1975 (75).

At the first meeting of the control group, it was decided that the group would meet once a week to make observations. These were to be made in connection with the shrinkage measurements that were also going to be made once a week. To be able to systematize the observations, a reference system and a special nomenclature had to be agreed upon. These tasks were assigned to the appointed secretary.

The Control Group starts its work

During the following week, on 22 January 1975, the control group held its second meeting. The method and strategy of performance were discussed. Both the outside and the inside of the hull were to be surveyed. For that day´s inspection, the strategy of a general survey followed by close study and measurements was chosen. The outside of the Vasa hull was observed from four different levels in the pontoon superstructure. The first round of inspection was made from the pontoon, i.e. at the keel level of the hull, the second round was made from the scaffolding around the hull at a level above the lowest wale (wale No 9). The third round was made from the lower visitors´ gallery, i.e. the level of the row of lower gunports of the hull. The fourth round was again made from the scaffolding at the level of the row of upper gunports. The inside was inspected deckwise starting on the upper deck and the after-deck and going downwards to the upper gundeck, the lower gundeck, the orlop deck and the hold.

In the general survey, it was noted that the seams had started to open up especially between the wales and the planks below and above them. The openings were small in the starboard side but larger in the port side of the hull where the opening previously recorded by the conservation department was measured to be 2.5 cm. A second notation was that some of the dowels had just started to protrude from the planks of the outer planking. From the inspection inside, it was noted that the deckplanks of the upper gundeck had shrunk more than the deckplanks of the lower gundeck and that both had shrunk more than was calculated as space for caulking.

During the close inspection round, 26 notations were made regarding the outside and 45 regarding the inside of the Vasa hull. The notations mostly concerned cracks and seams that were classified as "emerging cracks or seams", "plain cracks or open seams" and "wide cracks or seams". Whenever it seemed feasible, measurements of width, depth and length of a crack or an opened-up seam were made. The term "wide" denoted an opening that was wider than one centimetre. Later a denomination of "very wide cracks" was adopted.

Twenty of the twenty-six notations on the outside of the hull during the first inspection were related to cracks. Only two of them were considered as emerging and two were considered as wide. The others were developed cracks but mostly quite small. Measurements were made on seven of the cracks or opened-up seams. Of the forty-five notations inside the measurements were made on thirteen items. Most of the items recorded inside the hull were cracks. Nine of these were noted as "wide" and two as "emerging".

The second inspection was made two weeks later on 5 February 1975. The minutes of the group (141) recorded that shrinkage of between 0.1 and 0.2 mm had occurred since the inspection group had started its work in January.

The inspection started by checking the recordings from the previous inspection, which verified that nothing further had happened with those items. A total of forty-two new observations on the outside and fifty-eight inside the hull were made during the inspection round and recorded. This added one hundred observations to the seventy-one from the first inspection.

The general survey was also extended with the observation that the tillerdeck had large gaps between the planks ever since it was replaced in 1967. The largest gap measured 2.5 centimetres.

The fourth meeting and third inspection took place a fortnight later on 19 February 1975. This was the first time that the external group member E. Kjellgren, from the Swedish Institute for Wood Technology Research, took part in the proceedings. The inspection was made according to the previous schedule, but the list of observations was arranged with the observations for each deck starting at the fore end and going aft.

One observation was that the wood had swollen to some extent, causing some of the previously recorded and measured cracks to close. This seemed to be confirmed by the shrinkage measurements that showed swelling at ten and shrinkage at five measurement points while eighteen were unchanged. The total of observations after the third inspection was seventy-one on the outside and one hundred and eighteen inside the Vasa hull.

However, there was some difficulty in interpreting and summarizing the observations made in the general inspection comprising the whole hull. Therefore the new member, Kjellgren, suggested that two outside sections, one on each side of the hull that were typical for the outside of the hull, and likewise sections on each deck inside the hull should be chosen for measurements and meticulous inspection. The chosen surfaces should also be photographed. The suggestion had been put to the museum director who was going to forward it to the Conservation Council.

The fifth meeting of the control group took place on 12 March 1975. At this meeting, it was decided not to carry out an inspection of the hull but to work on the idea of typical sections. The meeting decided after discussion that one section was not sufficient to represent a whole side of the hull and suggested instead two sections on each side of the outside of the hull. The areas chosen on the starboard outside were situated between the gunports Nos 1-3 and between the gunports Nos 17-19. The port side was represented by the areas between the gunports Nos 10-12 and between the gunports Nos 26-28. Each section was three metres wide and ranged from top to bottom of the side of the hull. The opposite surfaces inside the hull were chosen to represent the inside. The control group finished its meeting by inspecting the suggested sections.

Introduction of the Control Group to the Conservation Council

The Control group was introduced to the Conservation Council by the museum director at its first meeting in 1975 held on 14 March. He also informed the council that the Control group had been established by the Board of the museum (75, §3). The paragraph stated that the Control group would be composed of the heads of the Conservation and Vasa departments, L Barkman and L-Å Kvarning, the members of their staffs U Skenbäck, B Lundvall, A Stolth and J Blomman, and one external expert who was to be appointed by the museum director in consultation with the chairman of the Conservation Council.

The Board of the museum also confirmed the duties of the Control group. The group was given the duty of finding out every two weeks through measurements and visual survey whether shrinkage and deterioration of the shape of the Vasa hull was occurring. For each function, a written report was to be made as soon as possible after the function was finished, and distributed to the museum director and to the chairman of the Conservation Council. The measurements might be made more often if necessary (104). The museum director was authorized to give more specifications for the work of the Control group.

The secretary of the Conservation Council and the appointed member of the Control group Kvarning, gave details about the work already done by the group. He described the general inspections that had provided an understanding of the present state of the Vasa hull. He also reported that some representative surfaces had been defined that were to be more thoroughly inspected and measured to obtain information about the course of events. Those surfaces would be inspected and measurements made every fortnight, while the general inspection was planned to be carried out every three months.

The Conservation Council accepted the suggested changes in the working programme of the Control group and added that the programme might be changed if the group thought it feasible. The changes should be reported to the next meeting of the Conservation Council. Any alarming event should be reported to the museum director.

Work by the Control Group during 1975

After confirmation of its duties and working methods for the inspection of the Vasa hull, the Control group began its task. The sixth meeting took place on 2 April 1975 with the object of performing the first inspection of the selected sections. The previously discussed situations of those sections had been slightly changed for practical reasons. They had also been thoroughly tagged. The sections of the outside of the hull got the tags 1 - 4 and the opposite sections inside the hull got the tags 10 - 14, 20 - 24, 30 - 34 and 40 - 44. The units 0 - 4 denoted the decks in the order: upper deck, upper gundeck, lower gundeck, orlop deck and hold. The observed cracks were tagged with the designation of the section and numbers in consecutive order. During the first inspection of the selected surfaces, sixty-three cracks were tagged and measured for length. Special notations as to the possible course of events were made for a few cracks. In the course of starting work on the selected sections, Kjellgren also chose four places within those sections to make thorough measurements of tangential shrinkage with a specially built measuring device.

The next inspection of the selected sections took place a fortnight later. The cracks that had been tagged were again measured. Fourteen of those, i.e. more than 20% (22%), had grown in length during the period. There was however some difficulty in seeing the cracks properly because of the wetness of the wooden surfaces. This indicated that it would be necessary to have the spraying shut off during the night before an inspection.

The following inspection also concerned the selected sections. It was carried out on 21 May 1975, five weeks after the previous one. This time, the spraying had been stopped for twenty-four hours and this made it easier to see the cracks. Ten out of sixty-three cracks (16%) were noted to have grown in length.

On 11 June 1975, another general inspection was performed, about four months after the previous inspection of its kind. The observations were this time made easier by the fact that the spraying had been shut off so that the surfaces were dried up. As at the previous time of inspection, the seams on the outside of the hull had opened up but not to any considerably greater extent than before. One long crack was noted in the wale between the rows of upper and lower gunports on the starboard side of the hull. However the crack contained caulking which indicated that it had existed even before the Vasa sank. Inside the hull, the seams between the deckplanks had also opened up, as had already been observed during the previous inspection.

The work of the Control group and the result of the inspections were reported to the Conservation Council at the meeting on 25 June 1975. Schoerner remarked on the rather fast growth in length of the cracks that were measured. He also had some questions about the method of measurement. It was therefore decided that Schoerner should take part in the next inspection.

On 13 August 1975, the Control group and Schoerner from the Conservation Council gathered to make the inspection and to measure the cracks of the selected sections. A number of the cracks had grown since the last meeting, so that only about 25% of the tagged cracks had remained unchanged. The members of the Control group also discussed the shrinkage measurements, which showed an accelerated shrinkage from the beginning of May.

The selected sections were also the target of the inspection round on 17 September 1975. This time, the control group noticed that some cracks had joined each other and that made it difficult to know which one had grown. As a complement, it was suggested that surfaces that were completely devoid of cracks should be chosen on representative timbers. These surfaces should be scrutinized at every inspection to observe whether new cracks were developing. This idea was reported to the Conservation Council at their meeting on 23 September 1975.

The inspection on 23 October 1975, in which the museum director took part, would combine the general inspection and the inspection and measurements of the selected sections. The Control group noted that the combined inspection was the tenth inspection in all, the fifth general and the sixth inspection of selected sections (figure 8-1).

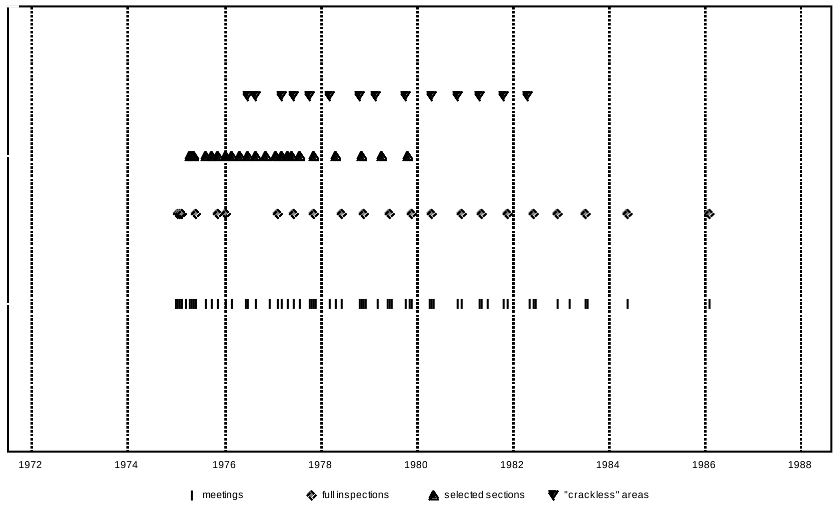

Figure 8-1 The meetings and inspecions carried out by the Control group for the state of conservation of the Vasa hull

The general inspection recorded the further opening up of seams. The earlier 2.5 cm opening between the wale No 6 and the plank above it had grown to 3.0 cm. The cracks in the selected sections had grown further and only about 15% of the originally measured cracks had remained unchanged.

Work by the Control Group during 1976 - 1978

The Control group made the first inspection of 1976 on 14 January. As on the previous occasion, it was performed as a combined general inspection and an inspection of the selected sections. The group noted few changes in the selected sections since the inspection made three months earlier. The general inspection registered rather severe cracks in some of the beams afore on the lower gundeck. Some widening of the opened-up seams was also noted both in the decks and on the outside of the hull.

However, the Control group reported to the meeting of the Conservation Council on 20 January 1976 (106) that no noteworthy changes had been found since the previous inspection. The Control group also suggested that twenty-five clearly defined areas with no cracks should be selected to be scrutinized for emerging cracks at the next inspection.

The second inspection in 1976 took place on 18 February and was an inspection of the selected sections. There was some discussion about the way of starting up the project in the areas without cracks. The report to the Conservation Council (108) said that no notable change had occurred.

During the rest of 1976, the Control group carried out four inspections of the selected sections without finding anything to report other than minor changes in either direction.The first inspection of the areas without cracks to ascertain the state of those areas was completed on 22 June 1976. Twenty-two areas with very small cracks had been thoroughly described.

On 23 August, the fifth inspection of 1976 took place. It comprised the selected sections and the "crackless" areas. For both categories, growing and closing cracks were reported. The Conservation Council (109) judged the situation to be unchanged compared to the situation before the summer period.

During 1977, the Control group met nine times evenly distributed over the year. At eight of these meetings, inspections were performed. General inspections were made in January, June and November. There were six inspections of selected sections. The areas without cracks were scrutinized in March, June and October.

The situation was discussed by the Conservation Council, where it was stated that a number of cracks had developed and that some of them were wide. At the meeting on 5 August 1976 (112), there was a lengthy discussion about the possibility that the large cracks might have developed because of strain in the construction. Schoerner suggested monitoring the position of the hull from the concrete elements of the pontoon superstructure with a laser beam. The meeting charged him with the task of investigating the possibility of doing this.

Another cause of cracking might be the specific structure that was a result of the growth of the tree from which the element was cut. In such a case, it would not be possible to ease the strain by conservation treatment. The meeting suggested that the expert, Per Nylinder (Royal College of Forestry), should be called to give his opinion.

There was also the important question of the influence of the severe crack on the strength of the hull construction. The chairman (Thunell) pointed out that lengthwise cracks did not greatly affect the strength. However the meeting suggested that the expert, Bengt Norén (Swedish Institute for Wood Technology Research), should be called in to give a second opinion. At the following meeting (113) on 9 December 1977, Schoerner reported that he had contacted Nils Abramson at the Royal Institute of Technology who was a specialist on laser measurements. Nils Abramson was going to investigate the possibility of making laser measurements in order to obtain information about the stability of the shape of the Vasa hull.

The question of the strength of the hull construction had been answered in a written report by Bengt Norén (51). He recommended some strengthening of the beams that carry the upper deck. He suggested that the beams that needed strengthening should be reinforced by a T-section iron beam along their full lengths. The need for this was to be considered later.

The expert on wood material, Per Nylinder, took part in the meeting and gave his general opinion on the influence on wood of a lengthy stay in a water environment. He also inspected the situation on board the Vasa and gave the opinion that there was no grave danger, even though there were some large cracks. On inspection of large cracks in a knee he pointed out that the bolts seemed to have changed the strain in the wood and that this might have caused the cracks.

The reports from the experts made the Conservation Council feel safe to recommend that the conservation programme should continue as planned.

During 1978, the control group had seven meetings and carried out six inspections. Two of these were general inspections, two concerned the selected sections and two concerned the "crackless" areas. At the last meeting for the year of the Conservation Council (115), the reports from the inspections were considered. The meeting noted that a number of newly opened up wide cracks in the beams and other heavy timbers in the hold and orlop deck had been registered.

Inspection Work by the Control Group and the Conservation Council during 1979

The spraying was stopped in January 1979, and this called for close attention to the hull. On 20 and 23 February, the Conservation Council met to inspect the inside and outside surfaces of the hull. The observation was that the relative humidity both inside and outside the ship had varied between 65 and 70%, which was the council´s recommendation. Although this RH-level was the lowest ever to have been applied in the hold, no sudden change in the shape of surface checking or cracking had occurred. The recommendation of the Conservation Council was that the relative humidity should be kept at about 70% and that the drying should be allowed to continue for a period of time before any decision about the starting point for the final surface treatment could be taken.

The Control group also started its work on 23 February 1979 with an inspection of the "crackless" surfaces. From this inspection, fourteen new cracks were reported. In April, the selected surfaces were inspected and in June a general inspection was made. After that inspection, the control group made a synthesis of the observations made up to that time (142). In this report, the Control group noted with regard to the general inspection that the total of observations had risen from 468 to 582 during the spring of 1979. Most of the new observations belonged to the two gundecks. Widening of cracks was also noticed in this area. The selected surfaces where measurements were made showed, in contrast, movements in both directions. The previously mentioned fourteen new cracks that had been registered on the "crackless" surfaces were all situated in the gundeck area.

The Conservation Council had taken on the duty of assessing the condition of the surface of the hull in order to advise on a suitable point of time to start the final surface-consolidation treatment. They were also to look into the proposed way of performing the final treatment through an examination of the treatment of the long boat that had been made as a pilot project. The experts had presumed that it would be possible to establish this during the three-month period directly after the spraying had been stopped. The drying of the wooden surfaces of the Vasa hull was on the agenda at every meeting of the Conservation Council and at the meeting held on 11 May 1979, the Conservation Council found that the long boat seemed to have responded well to the four coatings of PEG 4000 solution that had been applied to it and that the wooden surfaces of the Vasa hull were sufficiently dry to receive treatment. On those grounds, the Conservation Council recommended that a defined surface should be sprayed with PEG 4000 solution as a test. This should be done at the end of May and the Conservation Council would inspect the treated surface about a week later (118).

At their next meeting on 7 June, the Conservation Council drew up the lines for further testing of different concentrations of PEG solution. At that meeting, it was reported from the general inspection carried out by the Control group on 1 June that the number of cracks registered on the upper and lower gundecks had grown and also that the earlier registered cracks had grown in that region. This report led the Conservation Council to respond to the written proposal by Håfors to raise the relative humidity. The recommendation from the Conservation Council was that the RH value both around and inside the hull should be kept at 75% starting on 7 June (119, §3). A month later, before the meeting, the members of the Conservation Council inspected the treated surfaces. They observed some sweating of the

PEG and therefore recommended an RH-level of 71-72% in order to keep the surface dry. It was recommended that the RH be lowered to the previous level of 70% at the meeting on 27 August 1979 (chap. 5).

It was still necessary to fix the time when the final surface protecting treatment should be started. This was finally given as 8 November 1979 when it was recommended that spraying the first of three to four coatings of PEG 4000 should be carried out.

Inspection Work by the Control Group during 1980 - 1986

In all, there had been about ten inspections to certify the status of the Vasa hull during this first year after the automatic spraying was stopped. These were carried out by the Control group, and also by the Conservation Council. In 1980, the Control group continued with its general inspections and inspections of the "crackless" areas, while the inspections of the selected areas were abandoned because the cracks had extended beyond the boundaries of the sections (143).

During 1980, the Control group made two general inspections and two inspections of the "crackless areas". At their meeting on 13 May 1980 to review the situation, the Control group stated that the lower gundeck, the orlop deck and the hold were the areas where cracks had been developing and widening since the beginning of 1979 (143). At the corresponding meeting on 5 December 1980, it was stated that the development of cracks had almost ceased. On the other hand, there had been a manifest opening-up of seams especially of the inner planking and the decks during 1980 (144).

In 1981 the same schedule for inspections was kept, with two general inspections and two inspections of the "crackless areas". At the end of 1981, the Control group stated that the opening-up of seams had continued, especially in the area of the hold. In contrast, on the upper gundeck, the seams were closing to some extent (145).

In April 1982, the last inspection of the "crackless" surfaces was carried out. The Control group came to the conclusion that the recorded changes were marginal and might be considered to be an error in measurement. The group therefore decided, in agreement with the Conservation Council, that the inspection of the "crackless" areas should be discontinued (146).

The two scheduled general inspections were nevertheless carried out, one in the spring and one in the autumn of 1982. In the following years 1983, 1984 and 1985, only one inspection was made each year. As there were no great differences between the notations recorded in these inspections they were also discontinued. The last inspection was carried out at the end of December 1985 (figure 8-1).

Measurements made during the Inspections

The object of the inspections was visual assessment, and measurements were not included at first. With the establishment of the selected sections, however, measurements came into the project and such were adopted in all three types of inspection.

The positions chosen for the shrinkage measurements with the E Kjellgren-instrument were the upper gundeck and the corresponding situation on the outside, and lower gundeck and at a considerably lower position on the outside where practical considerations had favoured a position reachable from the pontoon.

The measurement showed a declining shrinkage from the start of the measurements to the end at the two highly positioned measuring points. The total shrinkage amounted to only one per cent in those two cases. The two lower measuring points showed parallel shrinkage patterns, with the highest shrinkage at the lowest situated point. However, at the end of the measurement period, they had each shrunk by four per cent. More than half the shrinkage, 2.2% for the point at the lower gundeck and 2.8% at the low position on the outside, had occurred by the end of 1976. There was then a stationary period during the winter of 1976 to 1977. The shrinkage started again about March 1977 (figure 8-2). This is when the rounds of spray treatment were cut down from two per 24 hour period, which had been the schedule since October 1975, to only one in the same period of time.

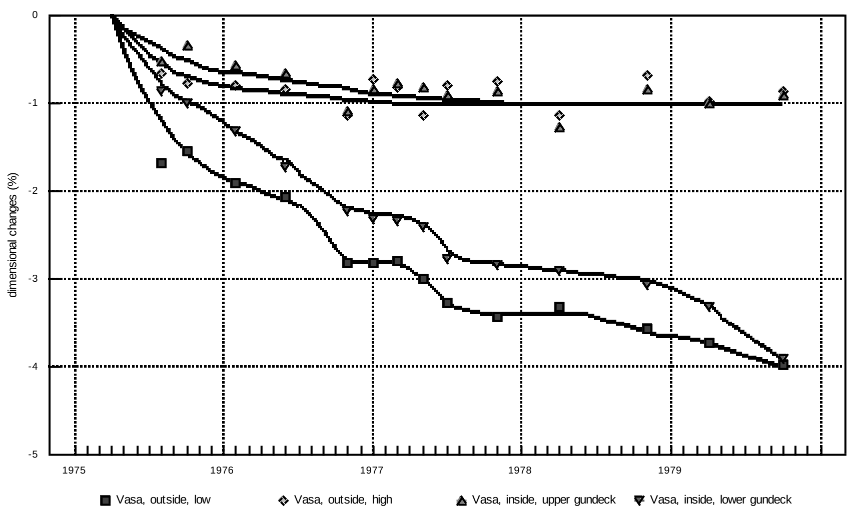

Figure 8-2 Measurements of Dimensional Changes with the E Kjellgren - instrument

The lengths of cracks were measured only during the inspections of the selected sections. Different patterns in the growth of cracks might be expected in different parts of the Vasa hull as a result of different drying situations. From the records it is possible to separate the measurements into two main groups, measurements on the outside of the hull and measurements on the inside. Those on the inside can be further separated in accordance with the deck compartment to which they belong.

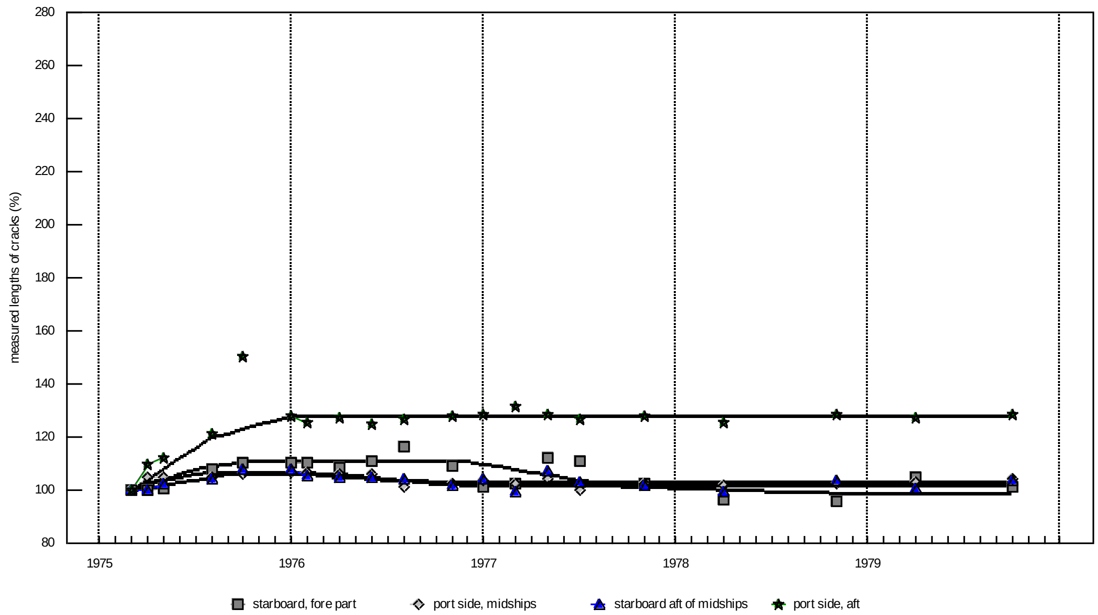

Figure 8-3 Selected sections; change (%) in length of cracks on the outside of the Vasa hull

The lengths of cracks on the outside of the hull seem at first to grow slightly, but the growth came to a standstill late in 1975 or early in 1976. This condition was the same in all four of the selected sections on the outside. From the beginning of 1976, the measured cracks in the midship sections on both the starboard and port sides started to close and they reached a stable state very similar to the starting conditions at the end of 1976. The measured cracks on the starboard, fore part section started to exhibit the same closing movement at the beginning of 1977, which finally led to the same condition as at the starting point. The lengths of the cracks in the section on the port side aft did not, however, change during the rest of the measurement period (figure 8-3).

The inside sections showed at first a pattern similar to that of the outside sections. The cracks grew in length and then came to a standstill (figure 8-4). This happened late in 1975 in the section on the port side aft, at the beginning of 1976 in the section on the starboard side aft of midships, and a little later in the section on the starboard fore part. The cracks in the section on the port side midships stopped developing in the autumn of 1976.

During the rest of the measurement period, the cracks in the two port side sections remained at the same length as they were before 1977. In the two starboard sections, however, the cracks started to grow again, the one in the autumn of 1977 and the other early in 1978. Close examination of the notations at each deck level reveals that cracks were growing rapidly in the hold and in the orlop deck compartments. This might be a precursor of the recorded growths of cracks in those regions during 1978 and 1979.

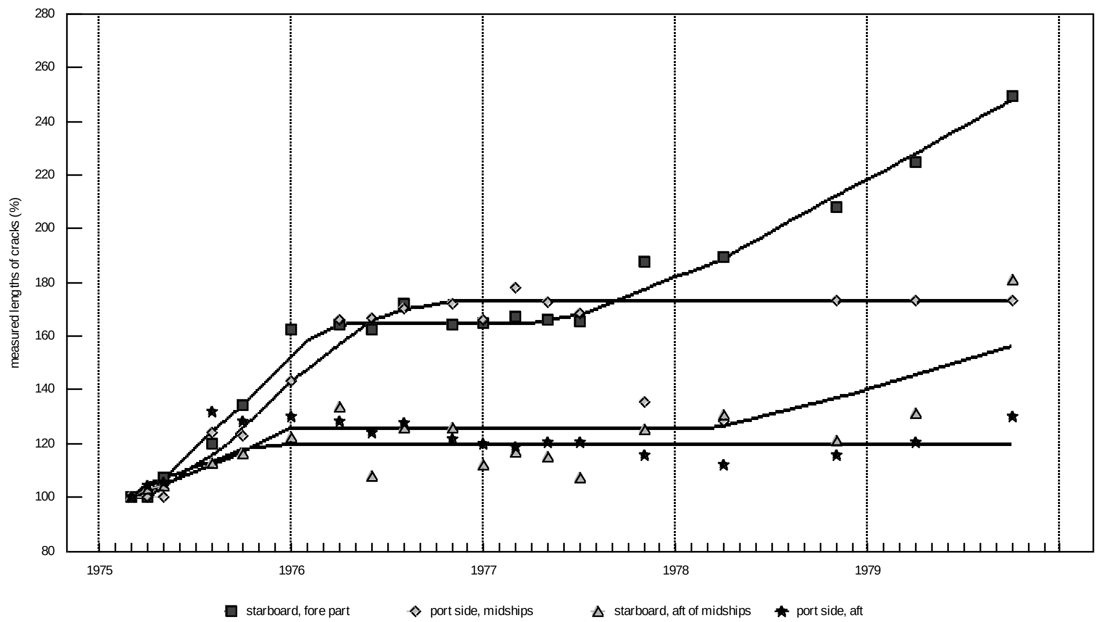

Figure 8-4 Selected sections; change (%) in measured lengths of cracks on the inside of the Vasa hull

In the selected sections, some cracks were also chosen for width measurement (figure 8-5). From the table, it can be deduced that two cracks had opened up already in August 1975. Their widths were 1.90 and 0.90 cm. The first two columns of the table show stationary or slowly developing widths of the two cracks for about ten months. In the summer of 1976, there was a sudden growth in width of both the cracks and then again a stationary period of nearly a year. The widths reached by the two cracks during the summer of 1977 then lasted for two years when there was a final record of an upward jump in the widths of these two and the other five cracks registered during the course of monitoring the selected sections.

The general inspections were conducted regularly for more than ten years. As this inspection was not constructed with a defined task from the start but was meant to be a total inspection, areas were defined when necessary for a proper recording of changes due to cracks, opened-up seams and other kinds of openings. The definition of new areas may thus be seen as a measure of the degree of change. Each of the defined areas might also hold one or more of the three phenomena to be recorded. The table of control areas (figure 8-6) shows a standstill in about seventeen defined areas during the first two and a half years. There was then a sudden development that called for almost a doubling of the number of defined areas. This was mainly due to the development of cracks (figure 8-6, column 2). The next increase of ten per cent in the number of defined areas came at the beginning of 1980. This time, the number of seams and other kinds of openings had grown. This was also the case two years later, at the end of 1982, when the increase in the number of defined areas amounted to fifteen per cent. Adding together the areas defined with cracks, opened-up seams and other openings, this last period of monitoring seems to point to changes in the hull construction rather than to a shrinkage of the wood.

inspection No	date	identification 10:1 (cm)	11:3 (cm)	12:2 (cm)	13:1B (cm)	31:2 (cm)	43:2 (cm)	44:2 (cm)
1	1975 04							
2	1975 04							
3	1975 05							
4	1975 08	1,90	0,90					
5	1975 09							
6	1975 10	2,00						
7	1976 01	2,10	1,00					
8	1976 02	2,30	1,00			1,40		
9	1976 04	2,40	1,00			1,40		
10	1976 06	2,70	1,10					
11	1976 08	2,90	1,40			1,50		
12	1976 11	3,00	1,40		1,00	1,50		0,80
13	1977 01	2,90	1,20		1,00	1,60		0,90
14	1977 03	2,90	1,40		1,00	1,60		0,93
15	1977 04	2,95			0,99	1,60		0,92
16	1977 05	3,00	1,33	0,66	0,99	1,70	0,51	0,94
17	1977 07	3,20	1,50	0,60	1,00		0,50	0,90
18	1977 11	3,20	1,54		1,00	1,48	0,60	
19	1978 04	3,20	1,50	0,70	0,80	1,50	0,61	1,00
20	1978 11	3,10	1,54	0,70	0,80	1,50	0,66	1,10
21	1979 04	3,20	1,60	0,72	1,02	1,50	0,84	1,20
22	1979 10	3,40	1,70	0,96	1,22	2,00	1,10	1,54

Figure 8-5 Selected sections; measured width of cracks from August 1975 to October 1979

inspection No	date	control areas	areas with cracks	of which those with large cracks	very large cracks	areas with seams	of which those with large seams	very large seams	areas with other openings	of which those with large openings	very large openings
		number	number	number	number	number	number	number	number	number	number
1	1975 01	10	8	2	0	1	0	0	1	0	0
2	1975 02	7	5	0	0	3	2	1	0	0	0
3	1975 02	17	13	2	0	4	2	1	1	0	0
4	1975 06	missing record									
5	1975 10	missing record									
6	1976 01	missing record									
7	1977 01	missing record									
8	1977 05	19	13	2	0	6	3	2	1	0	0
9	1977 10	30	23	5	0	7	3	3	1	0	0
10	1978 05	34	24	7	0	7	1	6	5	3	1
11	1978 11	36	24	7	0	9	3	6	5	3	1
12	1979 06	36	24	7	0	9	3	6	5	3	1
13	1979 11	36	24	10	0	9	3	7	5	3	1
14	1980 04	37	24	9	0	9	3	7	6	4	1
15	1980 11	40	25	9	0	10	4	7	7	5	1
16	1981 04	40	25	9	0	10	4	7	7	5	1
17	1981 11	40	25	9	0	10	5	6	7	5	1
18	1982 05	40	25	9	0	10	5	6	7	5	1
19	1982 12	40	25	9	0	10	5	6	7	5	1
20	1983 05	46	26	9	0	16	8	6	7	5	1
21	1984 05	46	26	9	0	16	9	6	10	7	1
22	1985 12	46	26	9	0	16	9	6	12	6	1

large = 10-25 mm   very large = >25mm

Figure 8-6 General inspection, round of inspection made from the keel level; number of identified areas with cracks, opened-up seams and other kinds of openings also specified as large and very large

As in the selected sections, the widths of some cracks, opened-up seams and other openings were measured in the general inspections (figure 8-7 through 8-10). Most measurements started in 1979, i.e. at about the time when the inspection of the selected sections was discontinued. Taking into account the information from the analyses of the defined areas, it is hardly surprising to find that there was practically no development in the widths of the cracks during that period. Instead there were some signs that cracks were closing (figure 8-7).

Inspection No	Date	Identification							
		UWSB Bh10 K5	UWSB Bh9-10 K27	UWSB stern	UWBB Bh9-10 rudder	UWBB Bh10 K22-20	UWBB Bh10 K16	UWBB Bh10 K12-(10)	UWBB Bh10 K10-8
		(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
1	1975 01								
2	1975 02								
3	1975 02								
4	1975 06	missing record							
5	1975 10	missing record							
6	1976 01	missing record							
7	1977 01	missing record							
8	1977 05				2,15				
9	1977 10								
10	1978 05				2,00				
11	1978 11				2,20				
12	1979 06				2,20				
13	1979 11	1,70	1,50		2,20	1,60	1,20		
14	1980 04	1,70	1,50		2,20	1,60	1,20		
15	1980 11	1,80	1,50		2,20	2,00	1,20	2,50	1,50
16	1981 04	1,80	1,60		2,20	2,00	1,20	2,50	1,50
17	1981 11	1,80	1,60		2,00	1,30	1,00	1,40	1,50
18	1982 05	1,00	1,50		2,00	1,20	1,00	1,50	1,50
19	1982 12	1,70	1,70		2,00	1,20	1,10	1,50	1,90
20	1983 05	1,70	1,70	1,90	2,00	1,20	1,10	1,50	1,80
21	1984 05	1,70	1,60	1,90	2,00	1,00	1,10	1,60	1,60
22	1985 12	1,70	2,00	1,90	2,00	1,00	1,10	1,60	1,60

Figure 8-7 General inspection, round of inspection made from the keel level; measured widths of cracks (Meaning of identifications: UW = the exterior of the Vasa hull, SB and BB = starboard and port sides respectively, Bh = wale, bpl = plank of the outer planking, K = gunport)

Opened-up seams had been one of the earliest observations when the Control group started their inspections. The measurement of the widths of opened-up seams started as early as at the beginning of 1977 (figure 8-8 and 8-9). Many of these were, already at the beginning, wide enough to be classified as wide, i.e. between 10 and 25 mm, or very wide, i.e. more than 25 mm. They very often seem to have kept the same widths for the whole period of measurement, or they have widened at certain times to move to another stable situation. This sudden reaction may be because the drying of the wood increases the stress in the material until it can withstand it no longer but suddenly changes its dimensions.

Inspection No	Date	UWSB Bh9-10 K11-13 bpl2-3 (cm)	UWSB Bh9-10 K11-13 bpl7-8 (cm)	UWSB Bh9-10 K13-(15) bpl1-2 (cm)	UWSB Bh9-10 K13-(15) bpl2-3 (cm)	UWSB Bh9-10 K19-21 bpl1-2 (cm)	UWBB Bh9-10 K20 bpl1-2 (cm)	UWBB Bh9-10 K20 bpl2-3 (cm)	UWBB Bh9-10 K16 bpl1-2 (cm)	UWBB Bh9-10 K16 bpl7-8 (cm)
1	1975 01									
2	1975 02									
3	1975 02									
4	1975 06	missing record								
5	1975 10	missing record								
6	1976 01	missing record								
7	1977 01	missing record								
8	1977 05					2,7	2,5	1,8	2,0	
9	1977 10				2,8	2,7	2,7	1,8	1,7	
10	1978 05				2,3	3,2	3,2	1,9	2,1	
11	1978 11				2,3	3,2	3,4	2,0	2,1	
12	1979 06				2,4	3,2	3,4	2,0	2,1	
13	1979 11			2,8	2,5	3,2	3,6		2,5	
14	1980 04			2,9		3,2	3,8	2,0	2,5	
15	1980 11	3,0		2,9		3,2	4,0	2,0	2,6	
16	1981 04	3,0		2,6		3,4	4,2	2,4	2,6	
17	1981 11	3,0		2,6		3,4	4,0	2,3	2,6	
18	1982 05	3,0		3,0		3,4	4,0	2,2	2,6	
19	1982 12	3,0		3,5		3,4	4,0	2,0	2,6	
20	1983 05	3,0	2,0	3,5		3,4	4,0	2,0	2,6	2,0
21	1984 05	3,0	2,0	3,5		3,4	4,1	1,5	3,0	2,4
22	1985 12	3,0	2,0	3,5		3,4	4,1	1,5	3,0	2,4

Figure 8-8 General inspection, round of inspection made from the keel level; measured widths of opened-up seams (first series) (Meaning of identifications: see figure 8-7)

Inspection No	Date	UWBB Bh9-10 K12-8 bpl1-2 (cm)	UWBB Bh9-10 K12-10 bpl1-2 (cm)	UWBB Bh9-10 K10 bpl2-3 (cm)	UWBB Bh9-10 K10 bpl3-4 (cm)	UWBB Bh9-10 K10 bpl4-5 (cm)	UWBB Bh9-10 K8-4 bpl1-2 (cm)	UWBB Bh9-10 K8-4 bpl2-3 (cm)	UWBB Bh7 K4 (cm)
1	1975 01								
2	1975 02								
3	1975 02								
4	1975 06	missing record							
5	1975 10	missing record							
6	1976 01	missing record							
7	1977 01	missing record							
8	1977 05	2,1						2,6	
9	1977 10	2,2						2,7	
10	1978 05	2,4						2,5	
11	1978 11	2,5		2,0	1,5	1,1		2,8	
12	1979 06	2,5		2,0	1,5	1,1		2,8	
13	1979 11	2,5		2,0	1,5	1,8		2,9	
14	1980 04		2,6	2,2	1,8	1,8	2,2	3,0	
15	1980 11		2,8	2,4	2,0	1,9	2,2	3,0	1,2
16	1981 04		2,8	2,1	1,6		2,7	2,8	2,4
17	1981 11		2,5	2,1	1,6		2,2	2,8	2,4
18	1982 05		2,5	2,1	1,6		2,2	2,8	2,4
19	1982 12		2,5	2,5	1,6		2,8	3,2	2,4
20	1983 05		2,5	2,5	1,6		2,8	2,8	2,4
21	1984 05		2,5	2,5	1,7		2,8	2,8	2,4
22	1985 12		2,5	2,5	1,7		2,5	3,3	2,4

Figure 8-9 General inspection, round of inspection made from the keel level; measured widths of opened-up seams (second series) (Meaning of identifications: see figure 8-7)

The last kind of openings recorded is of a great variety. Their development is due to the shrinkage of the wood. Some of these develop between structural members, but others are openings between specimens that are not part of the framework. One example is recorded in the third to last column of the table (figure 8-10). The whole opening seems to have disappeared suddenly, due in this case to an adjustment of the supporting structure.

Inspection No	Date	UWSB K5 (cm)	UWSB Bh10 K7-9(9-11) (cm)	UWBB Bh9-10 K24-22 (cm)	UWBB Bh10 K24-22 (cm)	UWBB Bh10 K18-16 (cm)	UWBB Bh9-10 K16 (cm)	UWBB Bh10 K12-10 (cm)	UWBB Bh10 K10-8 (cm)
1	1975 01								
2	1975 02								
3	1975 02								
4	1975 06	missing record							
5	1975 10	missing record							
6	1976 01	missing record							
7	1977 01	missing record							
8	1977 05								
9	1977 10								
10	1978 05								
11	1978 11		1,4	1,6			1,0	2,7	
12	1979 06		1,4	1,6			1,0	3,0	
13	1979 11		1,7	1,7			1,3	3,5	
14	1980 04		1,9	1,7	2,1		1,7	3,5	
15	1980 11		1,9	1,7	1,8	1,5	1,7	3,5	
16	1981 04		1,9	1,7	2,0	1,5	1,7	3,5	
17	1981 11		1,9	1,2	2,0	1,9	1,8	3,5	
18	1982 05		1,9	1,2	2,0	1,9	2,5	3,5	
19	1982 12		2,1	1,2	1,7	1,9	2,5	3,5	
20	1983 05		2,1	1,2	2,2	1,9	2,5	3,7	
21	1984 05	1,8	2,1		2,0	2,0	0,0	4,0	2,5
22	1985 12	1,8	2,1	1,0	1,6	1,8	0,0	4,0	

Figure 8-10 General inspection, round of inspection made from the keel level; measured widths of different kinds of openings (Meaning of identifications: see figure 8-7)

SUMMARY

The Vasa Project

The initiator of the Vasa project, Anders Franzén was a private researcher into sunken historic ships. He had devoted many years to archive studies and the practical work of dragging the bottom of the Stockholm habour to be able to locate the wreck of the Swedish warship Vasa that had capsized in 1628. When he had found the wreck in 1956, he introduced the project to the authorities. These were persuaded to make an investigation into the feasibility of both a salvage and a museum project. For this a special committee, "Vasa-kommittén" was created by the Swedish Government.

Raising the Vasa was thus an undertaking that was started after careful consideration. When the decision had been taken to raise the ship, a special organization, "Wasanämnden" was formed by the Swedish Government, to be responsible for the project for a period of time before this resposibility was transferred to the National Maritime Museum.

However, such an undertaking as the Vasa project had never before been accomplished and, despite the precautions, the institutions and people involved had to go through tough situations to be able to provide the economic and technical resources and to do it at the right time.

The Conservation Project

The Vasa project was at the beginning and for many years almost completely a conservation project. However, arrangements to show the Vasa to the public during the conservation period were made immediataly after the hull had been raised and continued during the whole conservation period. Preservation and drying of the wood were the main problems. The decision to keep the hull construction together in one piece made tank treatment unfeasible and spray treatment had to be chosen for the hull. The wooden material that had been disconnected from the hull as e. g. the sculptural adornment and the material excavated from the hull underwent the more effective tank treatment parallel to the spray treatment of the hull. As the conservation phase of the hull turned into a slow drying period the refitting of the sculptural adornment that had been preserved somewhat quicker than the hull could start. This work could be completed only after the Vasa ship had been moved to the permanent museum building.

The Vasa Hull on the Pontoon

To prepare for the salvage of the hull, repair work was performed under water. This made it possible to lift the hull to a position with the uppermost planks of the ship´s sides above the surface of the water. In this position the hull was floated on to the pontoon in the dry dock. When the dock was emptied, the support of the water was removed. This immediately called for other support and props were applied, some of them supporting against the dock sides. The pontoon however, soon had to leave the dock which meant that the propping against the sides of the dock had to be replaced. This was achieved by putting up steel bands going from loops in the pontoon up the sides of the hull. The steel bands had fastenings rather high up for

tall props standing on the pontoon. The tall props and the steel bands thus created a kind of cradle for the hull.

Strengthening of the hull construction itself by inserting new bolts into the about five thousand boltholes was also started without delay, although it took some years to complete.

A Continuous Process

The process of stabilizing the waterlogged wood would be by diffusion of preserving substances into the wet wood followed by controlled drying. To avoid surface cracks and to achieve an optimal diffusion process the surface of the wood had to be kept continously wet until the conservation treatment started. When the water was pumped out from the dry dock and the whole Vasa hull emerged into the atmosphere there was a sudden discontinuity in water supply to the wood which might cause the surface to dry. To avoid this, waterspraying was immediately applied. This was done automatically by pumping water through mounted perforated pipeline and tubing where this was possible but also by hand spraying with a fire hose. The effectiveness of waterspraying in an open air situation was however limited. A protective housing had to be built around the hull.

Maintaining a Continuous Process

The protective housing was designed with a heating system, installations for humidifying the air and a system for distributing conservation solution. Although the importance of starting the conservation process was recognised, the necessity of cleaning the hull took priority during the first period. However, the conservation treatment started before the cleaning was finished. Because it was in principle a hand spraying treatment which was not a continuous spray treatment, it was absolutely necessary to keep a high relative humidity in the atmosphere around the hull. This was performed by the humidifying system with the aid of compressed air distributing water as fine droplets in the atmosphere.

Choosing Polyethylene Glycol (PEG) as Preservative

Never before had conservation of such a huge archaeological wooden object as the Vasa hull been accomplished. Thus there was no experience to lean on. Nor was there any time for experimental work to find a totally new formula for the conservation of the Vasa wooden material. However, a group of specialists from institutions dealing with various aspects of wood and other materials that had been found during the excavation of the hull was permanently attached to the Vasa project, the Conservation Council. An inventory was made of conservation methods and preservatives in use. A thorough evaluation was made by the specialists as to the suitability of these for the Vasa oak wood. Two aspects were considered in that connection, dimension-stabilizing treatments and treatments to prevent the growth of microorganisms.

For dimensional stabilization of the wood, only two preservatives came into consideration, namely carboxymethylcellulose which had been used in Holland for about ten years for archaeological ship finds and polyethylene glycol (PEG) which had been introduced as a preservative for archaeological wood only a few years earlier by Bertil Centervall who worked in Lund, Sweden. Polyethylene glycol had proved to have a very good dimension-stabilizing effect but it had only been used for the tank-treatment of small objects.

To form a judgement about the possibility to achieve a good result with spray treatment, Rolf Morén, who had been working on the impregnation of recent wood with polyethylene glycol, was invited to provide information about the qualities of polyethylene glycol in that respect.
After a thorough penetration into the matter by the chairman of the Conservation Council, Bertil Thunell, polyethylene glycol with a mean molecular weight of 4000 was chosen for spray treatment of the Vasa hull and also for the tank-treatment of the rest of the large wooden objects.

When the automatic spray system was put into use there were technical difficulties of its functioning with polyethylene glycol 4000 so, after careful consideration, the PEG with molecular weight 1500 was allowed to be exchanged for the PEG 4000 but only for the spray treatment.

However research had been going on at the research and analysis laboratory that had indicated that lower molecular weight PEG´s were much more effective as dimension-stabilizers of the Vasa oak wood than the PEG´s 4000 and 1500. Parallel tests had also shown that the hygroscopicity of the PEG´s 1000 and 600 was not inexpediently high at the RH-level that was chosen for the permanent Vasa museum.

Combining the Polyethylene Glycol with Borates

The need for protection against microorganisms and fungi was undisputed. For this, the choice fell on borates that during that period were much tested for commercial use. The existent formulae however did not combine well with polyethylene glycol. The first task for the research and analysis laboratory, at that time consisting only of the head of that function, was to create a solution that contained both polyethlene glycol as dimension-stabilizing agent and borates for the control of microorganisms.

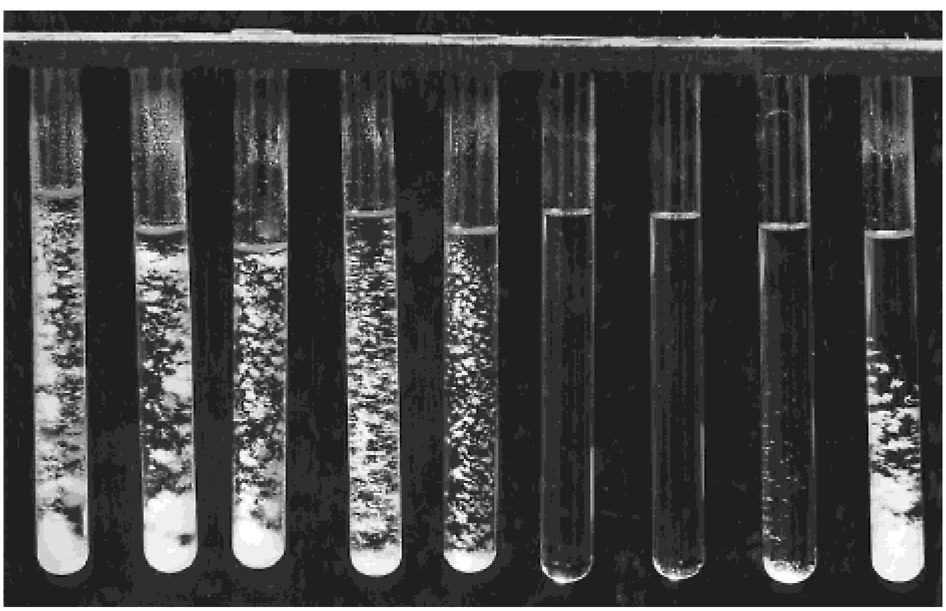

Figure 9-1 7%w/w of boric acid - borax mixtures 1:9, 2:8, ….9:1 in 30% PEG 4000 solution in water (photo: Gerhard Bauer)

To achieve this, solutions of combinations of boric acid and borax were prepared with pure water and a series of aqueous solutions of different concentrations of PEG´s 4000 and 1500 as solvent. The mixtures were tested first and foremost as to stability to precipitation but pH-values were also taken into account. The proportion of seven parts of boric acid and three parts of borax was found to work well with both PEG 4000 and 1500 and later also with PEG 600 (figure 9-1).

The Conservation Process

The process of PEG-penetration into the wood was monitored by boring core samples that were analysed for their content of preservatives.

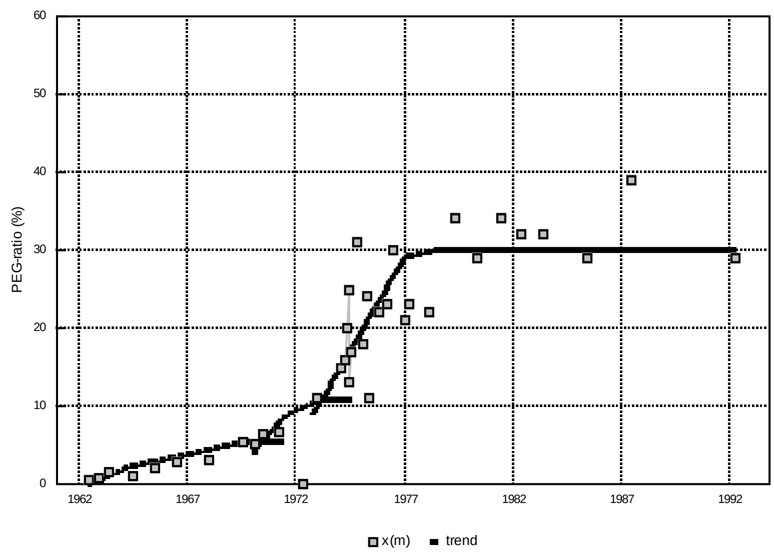

Figure 9-2 Outer planking, PEG-ratio (%) mean values and trend

The diagram (figure 9-2) shows that the uptake of PEG has taken place at different rates during three different periods. The periods are characterized by dissimilar automatic spray treatment. After the automatic spray treatment was stopped in 1979, a special surface treatment with PEG 4000 was made by hand-spraying.

When was the Time Right to End the Spray Treatment?

After three years, the hand-spraying system was changed for an automatic spray system that could ensure almost continous spraying of the surface of the wood, and the spraying was then kept running at full capacity for more than seven years. The plan for the conservation process was to make a change when the existing situation had come to equilibrium. During the full capacity spraying period, the concentration of polyethylene glycol in the conservation solution was raised from 10 to 25%. However, the monitoring by analysis of wooden cores from time to time gave a disappointing answer as to penetration of polyethylene glycol. This made the Conservation Council doubt the results of the analysis and, making judgments from other source material, they advised on speeding up the process. This was done and the conservation process was conducted in a way so that it came to an end in another seven years.

There was however a lot of disagreement about how to pursue and when to end the spray treatment. This eventually made the then head of conservation, Lars Barkman, hand in his resignation.

Relative Humidity in the Pontoon Superstructure

Keeping a high relative humidity (RH) in the atmosphere of the pontoon superstructure had been necessary during the first period of hand-spraying of the Vasa hull. The continuous running of the automatic spray system made extra humidification of the atmosphere unnecessary. However, when the spray treatment during the third period of automatic spraying was designed with longer and longer interrupting periods of drying, the atmosphere again had to be humidified separately. This time, a new installation working with steam was installed, that would allow a thorough control of RH through a span of RH-values from the high level necessary for ending the treatment period down to the RH-level chosen for the permanent Vasa museum.

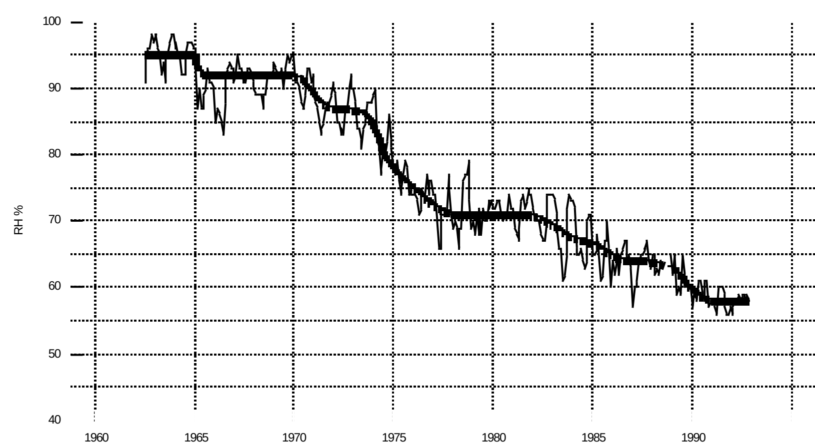

Figure 9-3 Recorded RH values and trend around the upper parts of the hull 1962 - 1992, monthly mean values

The relative humidity was recorded by a number of thermohygrographs. The readings from these are expressed as mean values per month and a trend has been constructed (figure 9-3). This shows a sometimes very large discrepancy in RH-values between the summer and winter periods in the pontoon superstructure, indicating that the external climate had a great influence on the climate within the pontoon superstructure. Nevertheless, the declining RH-trend during the period of intermittent spray treatment and the drying period is the result of a controlled lowering of the RH settings of the hygrostats. At the end of the period, an extra heating installation helped to modify the differences between the summer and winter periods by keeping a higher winter temperature than before inside the pontoon superstructure. In 1988, when the Vasa was to be moved to the permanent museum building, the level of 65% RH that was decided for the permanent museum had been maintained for about two years in the main part of the pontoon superstructure.

The Drying Procedure

It had been noted that the drying process had gone on almost since the spray treatment started. It was rather slow but noticeable during the period of continuous spraying. However, during the period of intermittent spraying with simultaneous raising of the PEG concentration in the conservation solution, the moisture ratio of the outer planking sank from 70 to 40% (figure 9-4).

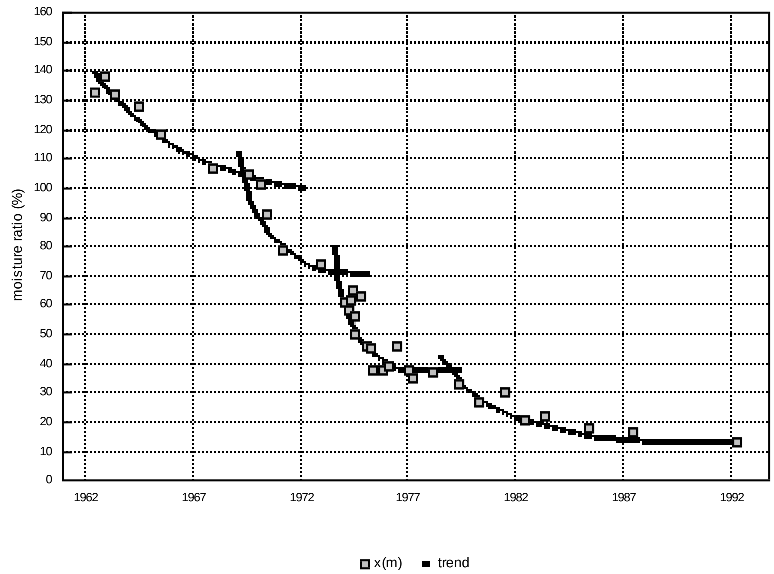

Figure 9-4 Outer planking, moisture ratio (%) mean values and trend

After that, little happened before the spray treatment was stopped in January 1979 and the controlled drying was started. That meant bringing the RH-level of the pontoon superstructure down from about 70% to 65% RH. This was done rather slowly, mainly during the period from 1982 to 1986 (figure 9-3). During that period the moisture-ratio of the wood of the planking sank to 15% (figure 9-4).

Monitoring by the analysis of core samples provided information about the drying of the wood but it did not say anything about the effects of drying on the wood. Because the purpose of the conservation was mainly to avoid shrinkage this has been monitored since 1966. The method has been to measure the distances between pairs of probes that have been hammered rather deep into the wood of the plankings. The measurement was made with a vernier caliper.

The shrinkage registered during the period of continuous spraying was less than 0.5% (figure 9-5). During the period of intermittent, spraying the shrinkage accelerated and reached a mean value of nearly 4% by the end of 1975. During 1976, the rate of shrinkage slowed down and came to a rest at 4.4% which lasted until the spray treatment was stopped in January 1979. During the period of lowering the RH in the pontoon superstructure from 70 to 65%, the plankings shrunk rather slowly by another 1.5%. The mean total shrinkage of the plankings was 5.9% when the Vasa was brought into the permanent museum.

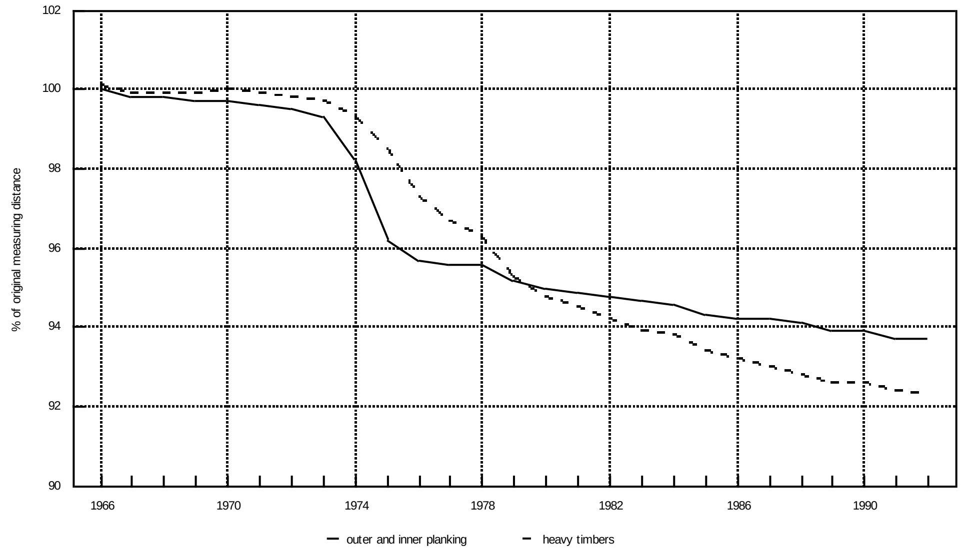

Figure 9-5 Shrinkage of outer and inner plankings (continuous line) and heavy timbers inside the Vasa hull (broken line) 1966 - 1992

A Steady State of Survival

The aim of a steady state of survival could not be achieved in the pontoon superstructure. The Vasa ship had to be housed in a high quality building with a complete air conditioning installation. This had been foreseen as early as 1957 in the instructions to the Vasa committee. The permanent Vasa museum building and the capacity of its installations had been discussed by the Conservation Council from 1981. In 1986 construction of the permanent Vasa museum was started. The museum includes the dry dock of Galärvarvet in its building which eased the problem of moving the Vasa ship into the museum.

The wood experts on the Conservation Council stated that a steady state of survival of the Vasa ship and loose wooden objects could only be assured if the moisture content of the preserved wood was kept stable and at a suitable level. The experts first recommended 12% that is established among wood experts as a suitable moisture ratio for long term survival of wood. This however required an RH level of 65% in the museum atmosphere. The designers meant that this would be unsuitable for the museum building and would require building materials that would add to the costs to a great extent. The Conservation Council then reconsidered and stated that moisture ratios of 11% or even 10% would be sufficient. Referring to the largeness of the Vasa hull and the difficulties of keeping the same values of RH and temperature in all parts of the museum, the experts specified moisture ratio values between 10 and 11 % for the long-term conservation of the Vasa wooden material. The Conservation Council stressed however the importance of total stability of moisture content in all parts of the Vasa wood.

The problem of establishing the values of RH and temperature for the ventilation air to create an atmosphere in the museum that could assure the steady state of survival of the Vasa ship was then attended to. The recommended 11 and 10% moisture ratio in the wood meant 60% RH at 20 °C which were the accepted values for the museum climate during the summer period. There was however still a wish for rather low RH values in the museum building during the winter for the safety of the building. It was therefore decided to lower both the RH and the temperature to maintain the same moisture ratios in the wood in the winter as in the summer. The RH/temperature pair first chosen was 57% RH and 17 °C. Regular weighing of some test material however showed weight losses during the winter period. To counteract this, the RH-value has been raised in a couple of steps to 58.5%.

Since the opening of the Vasa museum in 1990 there has been a further slight shrinkage, giving a total of 6.2% for the plankings in 1992 as an answer to the lower value of the moisture ratio than was planned when leaving the pontoon superstructure.

The planking had kept the same level of shrinkage for about a year, thus indicating that equilibrium had been established. This was however not the case with the heavy timbers. Not surprisingly they were somewhat slower in drying and this meant that the impact of the change of climate came later, so that their period of shrinkage has been longer than that of the plankings.

Monitoring shrinkage and other characteristics of importance continues as a routine feature of the maintenance programme. Evaluation of the conservation situation at regular intervals ensures that every change is noted and that proper action is taken to the secure long-term survival of the Vasa.

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Abstract in short: 1626 and 1627 a new lightweight (1200 - 1300 tons a piece) type of 24-pound cannon was cast for the Swedish Army and Navy. According to sources the Vasa was equipped with 48 of those. They were marked with the letters G. A. R. S (Gustaf Adolf Rex Sueciæ) and the year of casting.

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