A Novel Intelligent Pipe Protection System Used for the NordStream Pipeline Construction

*By M. MAGERSTÄDT**

The NordStream Pipeline Project

To link Russia and the European Union via the Baltic Sea, a set of two parallel new pipelines of 48″ ID is under construction. It will connect the world's largest gas reserves with the European gas pipeline network, NordStream will be significantly contribute to long-term security of European gas supply and of the energy partnership between the European Union and Russia.

The first of two parallel pipelines is scheduled to commence operation within this year. Each line is approximately 1220 km long, providing a transport capacity of some 27.5 billion m^3/a. Full capacity of about 55 billion m^3/a will be reached in the second phase, when the second line is operational.

NordStream is the leading – and timewise the first – of all new European gas supply pipeline projects. Pipelaying to date is on schedule despite the huge logistical challenges this project posed.

NordStream applied a comprehensive Logistics Concept for implementing the pipeline project. To ensure the most efficient pipelaying process possible for the NordStream project, a customized logistics infrastructure in the Baltic Sea region was required. In this logistics concept, weight coating plants, interim stock yards and trans-shipment facilities were included to minimize cost, time required, and environmental impact. NordStream is the largest offshore gas pipeline project ever. It is also the first pipeline to be implemented in the Baltic Sea region, which means that a logistics infrastructure had to be developed from scratch (Fig. 1).

Minimizing transport distances, ensuring environmental viability, and allowing for best technical feasibility, NordStream has identified and established five logistics locations along the Baltic Sea coast. This has lead to a strong positive impact on the local and regional economies around these logistics centers, boosting local business and employment.

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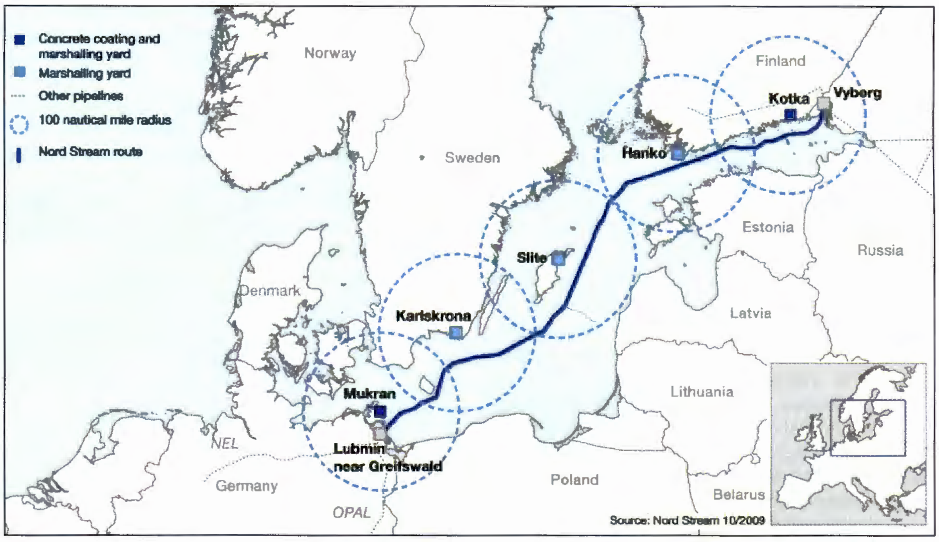

Fig. 1 Geography of logistics and right-of-way (Courtesy of and copyright by NordStream AG)

NordStream AG is an international joint venture established for the planning, construction and subsequent operation of this new offshore gas pipeline. Gazprom holds a 51% stake in the joint venture. BASF/Wintershall and E.ON Ruhrgas hold 15.5% each; N.V. Nederlandse Gasunie and GDF Suez are holding 9% each.

Intelligent Plastic Solutions

ROPLAST, a 100% subsidiary of the ROSEN Group, is one of Europe's largest manufacturer of cast polyurethanes. Under the trade name RoPlasthan®, high performance elastomers with an extended property range were developed over the last decade. Particularly the combination of elastomers and intelligent systems, e. g., the hermetic inclusion of a sensor unit into very sturdy RoPlasthan part, is a core competency of ROPLAST.

By synthesizing their own polyurethanes from raw materials rather than from commercially available multicomponent "kits", ROPLAST is able to offer customized elastomer property profiles for specific applications.

The ROSEN Group is a leader in non-destructive testing technology with a strong focus on in-line inspection of pipelines. The original contact between NordStream and ROPLAST originated from discussions with ROSEN about pipe joint inspection.

Nordstream: Logistics and Construction of a Very Long Subsea Gas Pipeline

At a length of 2 x 1220 km, a subsea pipeline construction project poses logistical challenges that neither occur with long land (underground) pipeline projects nor with other, shorter offshore pipeline projects.

NordStream, together with its contractors, is mastering these challenges excellently. To prove this, it should be mentioned that in 2010, the NordStream logistics team received the highly prestigious German Logistics Award ("Deutscher Logistikpreis") for the design and execution of this project.

What major logistical challenges had to be overcome?

Number of pipes

Obviously, more than 200,000 concrete pipe joints of 48″ diameter cannot be manufactured at a speed that allows delivery to the lay barges "just in time" to match the laying speed. In fact, pipe manufacturing of the first string of pipeline commenced approximately two years before even the concrete coating was started up, the latter coming into operation a little over a year before pipe lay-

ing begun. On the other hand, pipe joints for the second string are still being manufactured at this time when laying of the first string nears completion.
Whilst pipe manufacturing and interior / exterior polymer coating are done at various sites around the world, concrete coating is carried out at two of the mentioned five logistics locations at the Baltic Sea.
In summary, this means that pipe joints have to be stored at large stockyards at the five logistics locations over a long period of time, in some cases up to three years or even more.
For load-out, the pipe joints need to be
a) Clean on the inside, free of dirt, excessive amounts of water, animals, etc.
b) Free of corrosion on the cutbacks (uncoated areas) at both pipe ends
c) Free of defects caused by mechanical damage (or from fire) during storage
d) Individually marked and identifiable in the shortest possible time.

Pipe laying speed

Three lay barges are employed for the NordStream Project. Lay barges are very expensive to operate. With a laying time in the range of 2.4 km/d, the cycle time for each pipe joint is just a few minutes. Matching this time rhythm, new pipe joints need to be transferred to the lay barges from the five stock yards (by transfer barges). What this means is that quayside , there is almost no chance to "repair" any pipe joint that does not match conditions a) through d). Only a few minutes are available between arrival of the pipe joint at the quay and putting it on the barge. If a pipe is not in condition for load-out, it can only be set aside and taken care of later. This disrupts the logistics process and can cause significant additional cost.
Therefore, a "no-surprises" solution is mandatory that guarantees that all pipe joints arriving quayside match conditions a) through d).

Geographical distribution and stock yard size

With five yards in three different countries around the Baltic Sea, the sheer geographic dimension of the storage and handling process poses another significant challenge to logistics.
To guarantee that the pipes are not damaged mechanically (even by completely unintentional damage), not only would there have to be physical barriers, but also a rather large security personnel detail would be needed. Overall, a large effort including guards, fences, and other protective installations would become a rather expensive solution. While a smaller stockyard can be fenced in and be kept under surveillance rather easily, this is quite different here.
To prevent the pipes from becoming dirty or corroded, some kind of caps or closures need to be applied to each end of each pipe joint. To allow complete tracking and identification of each pipe, a system using barcodes or similar markings would have to be readable on the pipe joints in the capped / closed status as well as to open pipe joints where the protective covers have been removed. Since barcodes are normally applied to the pipe interior, it is not a trivial challenge to keep the pipe identification readable when the pipe joints are capped.

An Idea was born – History and Reasoning

How the idea was conceived

With the timeline for pipe manufacturing and preparation described above, the operator needed to be certain that no pipe that has any defect of that is dirty or corroded is loaded onto a lay barge. A "no surprises" philosophy had to be turned into a reliably operating protection system.
In this context, NordStream and the in-line inspection technology provider ROSEN discussed implementing a load-out inspection of each pipe at the point of load-out. This inspection (e. g., by pulling a wire line MFL or optical inspection tool through each pipe) would have needed to be done quayside. A "cycle time" of approximately 3–4 minutes, translates into a significant time strain on the inspection process. This very short cycle time would include bringing a pipe to the inspection station or setting up and removing inspection equipment at pipe stacks.
Before inspection, each pipe would need to be cleaned to remove dirt, debris, water and even desiccant packs (in case hermetically sealing pipe caps would have been used). Any varnish or dope to protect inner and outer pipe cutbacks from corrosion would need to be removed at this stage as well.
Not surprisingly, all cleaning steps, varnish removal, etc. would have amounted to a higher cost than the actual inspection itself. The overall cost of this process turned out to be prohibitively high.
The idea and its timeline:
- Only six months before startup of the first concrete coating plant, both partners conceived the idea to forego the inspection. Instead of cleaning and inspecting *after* storage, the pipes were to be protected from dirt, corrosion, and third party damage throughout the entire storage process from concrete coating to load-out. In a way that cleanliness and integrity of each pipe joint could be guaranteed at load-out. The system also would make it possible to track every pipe joint from concrete coating to load-out.
- As most sturdy and resilient protection material for Pipe Caps, RoPlasthan high performance elastomers manufactured by ROSEN`s subsidiary ROPLAST were chosen. Combined with this, an electronic system to allow pipe joint tracking and detection of third party damage was included in these caps. In addition, a number of features to prevent water accumulation inside the pipe, to prevent outer cutback corrosion and to enable wireless data transmission were included. Two pipe strings are being laid consecutively; hence, the cap system was designed to be re-used for protection of the second pipeline.
- Within three months of conception of the idea,
  - manufacturing equipment for the cap system, including moulds, polyurethane casting machinery, electronic boxes
  - mounting machines to mount the caps onto the pipe joints (to make sure that all

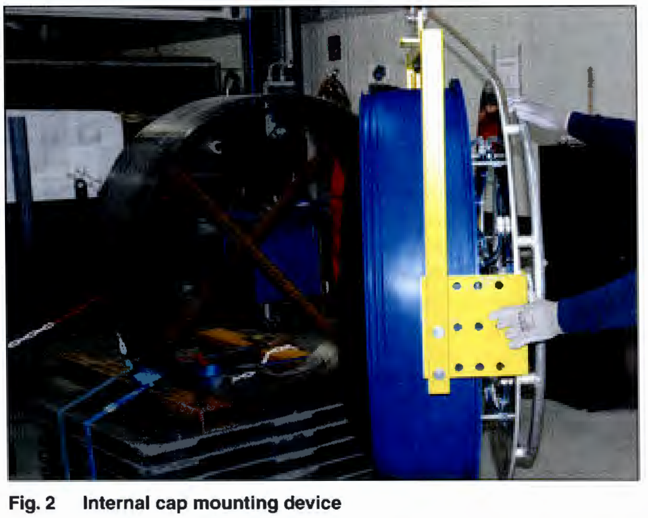

Fig. 2 Internal cap mounting device

Fig. 3 External cap mounting device

caps are mounted correctly, an automated process was conceived, Figs. 2 and 3)
have been developed and construction of the equipment had begun.
- After five months, the operator approved and validated fully functional caps, proprietary mounting devices, electronic systems including wireless data transmission and central control systems.
- After six months, concrete coating operations commenced which meant that commercial cap delivery and cap mounting on a large scale started. The wireless data transmission and central control systems were started up.
- Repeated audits by the operator, their contractor, and third parties before and during operation were passed successfully.

Reasoning / requirements

From the protection requirements for the stored pipe joints, the following specifications for a combined system were laid down:
- Corrosion protection of inner and outer pipe joint cutbacks
- Contamination protection of pipe joint interior including protection from condensation and accumulated water
- Protection from 3rd party interference (alarm function)
- Tracking of each individual pipe joint throughout the process
- Central data recording and real-time monitoring of all pipe joints over all five storage yards
- Re-usability for second NordStream pipeline string
- Altogether, some 210,000 pipes needed to be protected.

Protection of Pipes

Inner and outer cutbacks (blank steel) need to be protected from corrosion, i. e., rust formation. The Baltic Sea climate is particularly conducive to corrode unprotected steel.
The system consists of
- A two-part cap system ("inner and outer cap") made from RoPlasthan high performance polyurethane elastomer
- A membrane as part of the inner cap surface to allow passage of evaporated water while preventing passage of liquid water
- An electronic box mounted to the inside of the inner cap containing all sensors, an RFID chip for pipe joint identification, an energy storage device, and a wireless transmitter
- A wireless data transmission network with energy- self sufficient repeaters and a central control system.

The two-part cap system

Any simple, commercially available cap can protect the pipe interior from contamination. Inner cutback protection can also be achieved with such a cap.
All solid plastic pipe caps have the problem that the pipe interior would need to be protected against condensation water caused by outside temperature changes. In theory, the amount of water condensing in a sealed NordStream pipe joint under atmospheric conditions and temperature cycles that occur at the actual storage yards can amount up to 32 liters (more than 8 gallons). Therefore, a solid cap leads to the need to put desiccant bags into pipes protected by such caps (which need to be removed before load-out, another time-consuming factor).
The pipe interior needs to be protected from water and ice, dirt, and debris. And even from bird's nests, insects, and small animals that may consider a pipe joint a good choice for a nest or lair.
The inner cap (Fig. 4) is made of RoPlasthan high performance polyurethane material of very high compressive strength. The cap reaches far enough inside the pipe to ensure that the arms of the hydraulic spreader bar, lifting the pipe joints weighing up to 29 t, do not damage the cap.
At the outer cap end, a collar provides the structural stability of the cap and to protect the bevel. The cap has a profile at its outer rim near the cap end to seal with the outer cap by a zip-lock mechanism.
Towards the inside of the pipe there is a second collar with sealing lips that will bend and create contact pressure when the cap is pushed into the pipe.
These seals create the necessary grip to the pipe interior to accommodate out-of-roundness and to seal efficiently throughout the design temperature range.
The inner cap also holds the E-box on its inside.
A membrane is covering the outward surface of the cap (Fig. 5). The membrane is molded firmly into the RoPlasthan to avoid rupture even at high wind loads. The membrane allows passage of moisture. It has a high tear strength and is UV-resistant.
The outer cap (Fig. 6) is a very flexible sleeve (elongation at break is 500%), made of RoPlasthan; approximately 65 Shore-A. The material is of high density and therefore has an extremely low oxygen-permeation rate, thereby assuring highest corrosion protection.
The outer cap spans an area from the FBE cutback to the outer collar of the inner cap. The outer cap seals very strongly to the smooth and thin outer FBE coating on one end. Sealing is similarly strong – via the zip-lock – to the inner cap. The diameter of the outer cap is smaller than the pipe O.D. By stretching this sleeve with the mounting machine, an even and very tight fit without air entrapments is achieved.

Fig. 4 Inner cap

Fig. 5 Membrane in inner cap

Safety and Security

The safety and security functions consist of
- The electronic box (E-box, Fig. 7) containing all sensors, a battery, the RFID chip, and a wireless transmitter
- The pipe tracking system (RFID-based)
- The data transmission system
- The central control system.

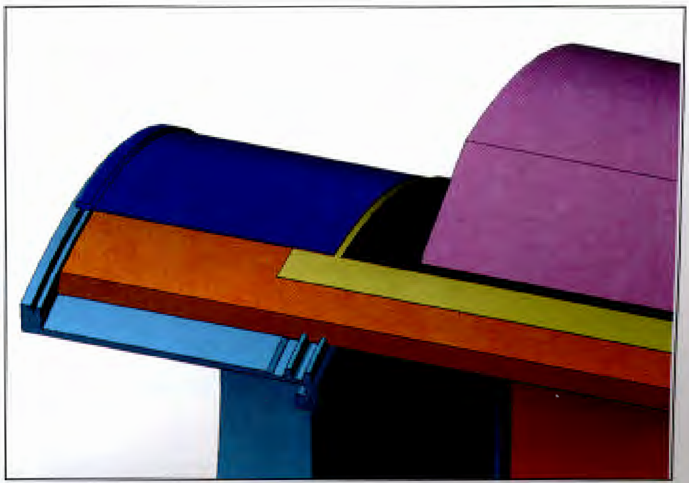

Fig. 6 Outer cap with inner cap zip-lock system

Fig. 7 E-box

Fig. 8 Transmission of pipe number from barcode to RFID chip

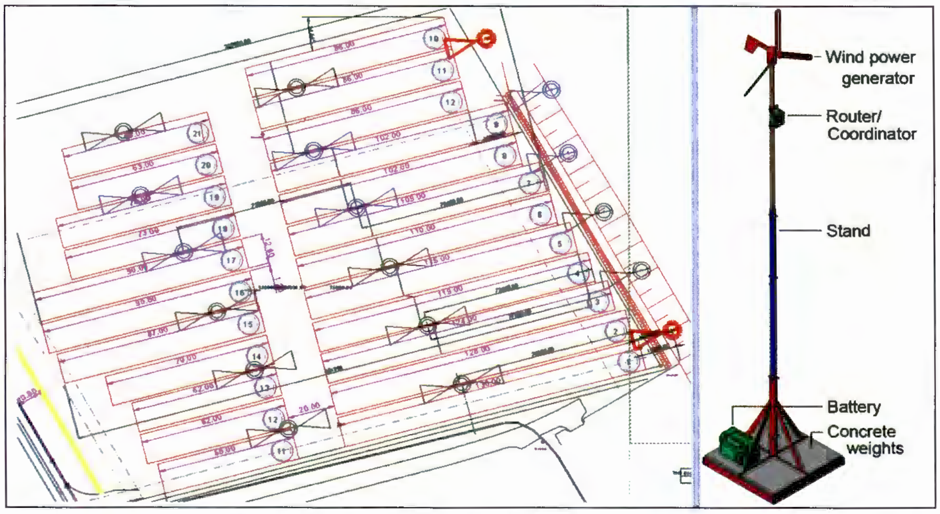

Fig. 9 A typical yard layout with router/repeater masts; right: self-sufficient router/repeater system

The E-box provides transmits alarms by RF transmission to repeaters (transceivers) located at each storage yard. Alarms occur when case any sensors are triggered. Every time, this happens, pipe number, type of alarm and time/date are transmitted. The E-box also sends "alive" signals at regular intervals. If the alive signal is not received on time or if the E-box malfunctions in any other way, an alarm is triggered as well.

Pipe joints arriving at the stock yards bear a barcode painted onto the internal coating near the inner cutback at both pipe ends. This barcode contains the pipe number for tracking. The ROPLAST Pipe Cap System enables complete tracking of each pipe joint based on this barcode number applied by the interior coater. The barcode number is read and uploaded to an RFID (near-field communication) chip contained in the E-box is during the cap installation process. To do this, a barcode reader/RFID writer is part of the cap mounting equipment (Fig. 8).

An intelligent self-assembling wireless sensor network was built as guarding system for the stored pipe joints (Fig. 9). This system is the first one in operation for such a large volume project. It transmits all alarms and alive signals from the E-boxes to the central control room. All transceivers are independent of the power grid and provide themselves with electrical energy by energy harvesting. In the NordStream project, as the main energy source for these transceivers, wind energy was chosen (Fig. 9, right). Rechargeable batteries on the transceiver masts can cover energy supply to the transceivers for several weeks in case there is no wind.

Considering the large dimensions of the stock yards described above, this solution provided by far the most comprehensive and most cost-efficient surveillance system.

Just like the E-boxes, transceivers also send "alive" signals so that transceiver failures are noticed immediately. In such cases, other transceivers automatically take over the function of the disabled transceiver. Simultaneously, an alarm is raised at the control center.

A central control software (ROPCMS) receives all communication from E-boxes and routers and analyzes the incoming messages. The system is able to differentiate and exclude all reports that clearly do not pose a threat. Only messages that do pass this test will cause an alarm message going to the operator (Fig. 10). Once an alarm message reaches the operator, security personnel is automatically dispatched for a physical investigation of the pipe joint in question. If necessary, the security personnel will quar-

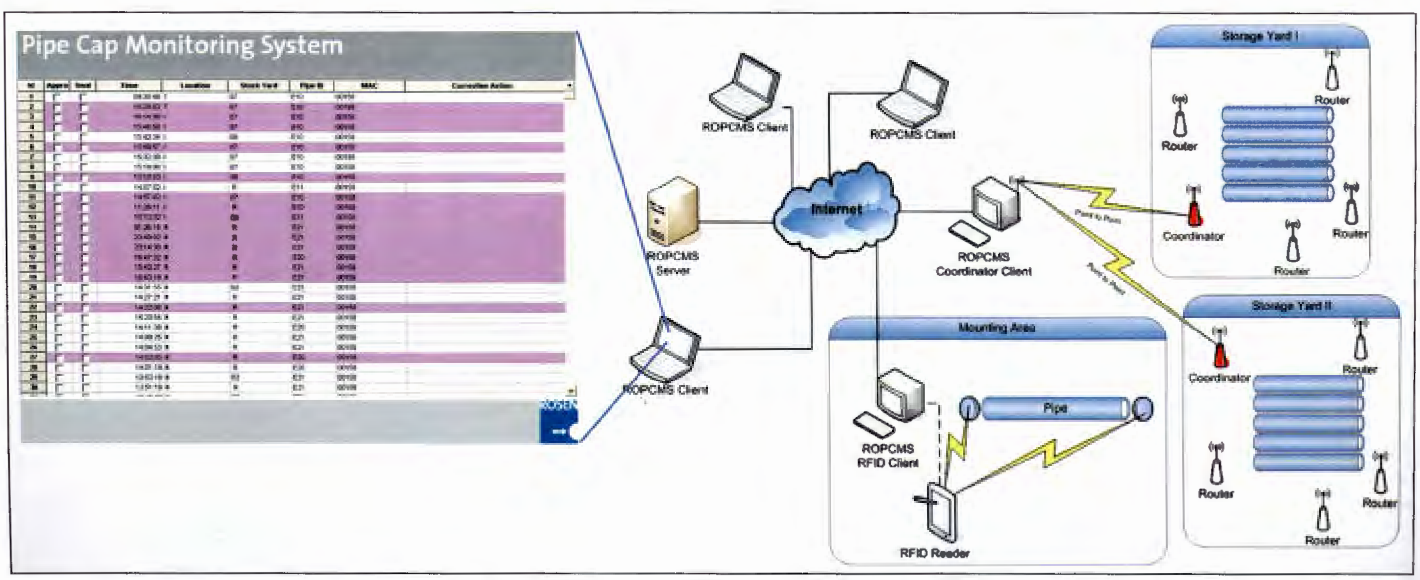

Fig. 10 Central control system (right) and user interface (left)

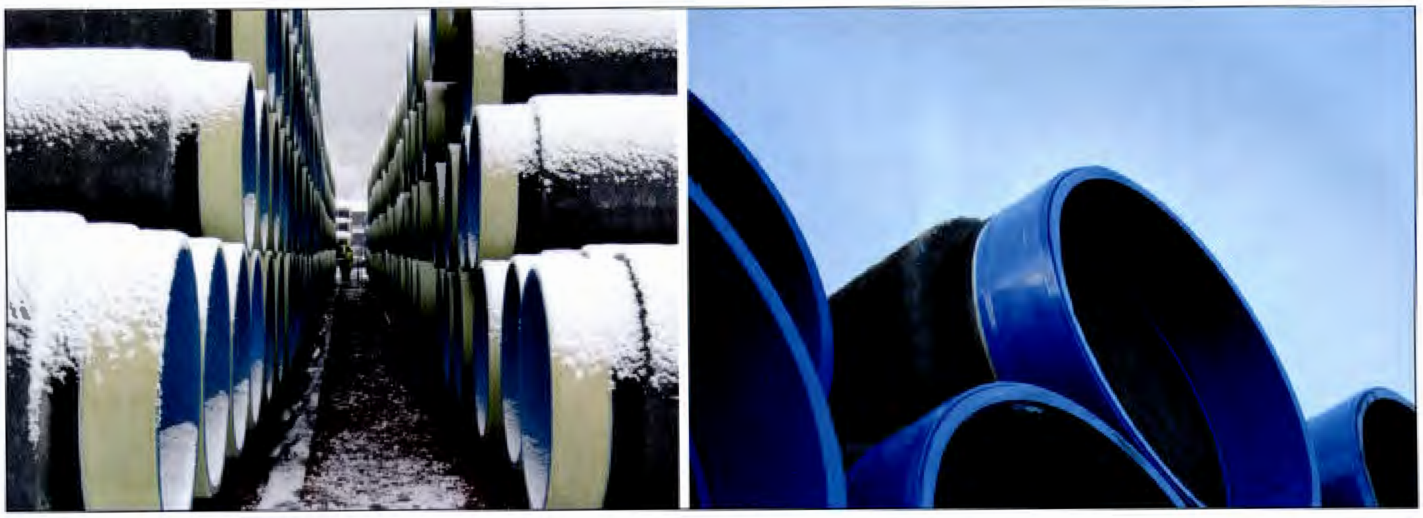

Fig. 11 **Capped pipes in storage yards**

antine this pipe joint so that it is not loaded out.
All data are recorded and can be traced back throughout the pipe construction project and afterwards.

Experience to date – At the Midpoint of Pipe Laying

The NordStream project is now close to mid-point of the laying process. The process of removing caps from pipes loaded out for the laying of the first pipe string and re-mounting these caps onto freshly concrete coated pipe joints for the second pipe string is in full swing.
With a very cold and snowy winter 2009/2010 and quite challenging weather this winter, the ROPLAST Pipe Cap System has proven its viability in a Nordic maritime environment. Even under sometimes very harsh weather conditions, load-out is progressing smoothly. – This novel system is a success.
The ROPLAST Pipe Cap System was designed and constructed in record time. From automated mounting and demounting to E-boxes, transceivers, and control center, all mechanical and electronic systems are fulfilling their functions.
Alarms have reliably been raised in the respective situations. Audits by the operator and by 3rd parties proved the correctness and reliability of the system.
RoPlasthan high performance elastomers have provided sturdy internal pipe protection as well as highly efficient protection of the inner and outer pipe cutbacks.
Audited quality systems were establish and contribute to functioning and reliable product.
Overall, this system means significant cost savings for the operator compared to conventional protection and surveillance systems.
Figure 11 shows examples from the field.

Scope

From today's experience, the two main advantages of the ROPLAST Pipe Cap System are
- Significant cost-savings whilst providing full traceability and full physical protection and
- Significant security enhancement.

Based on this system, ROPLAST is developing and marketing systems that
- Protect pipe joints and other valuable assets in very harsh environments (e. g. pipe laying projects in extreme climate conditions)
- Protect highly expensive technical goods during transport and storage whilst continuously monitoring conditions and integrity
- Allow tracking and recording of every component of a pipeline (or another technical installation) from the manufacturing of each component (e.g. from the batch in the steel smelter) to the finished, operating asset
- Continuously monitor (employing wireless sensor networks) assets in operation for security and protection.

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