Sheet Pile Corrosion in Swedish Harbours - An inventory of Corrosion Surveys along the Swedish Coast

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Sheet Pile Corrosion in Swedish Harbours – An inventory of Corrosion Surveys along the Swedish Coast

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Summary

This paper is a part of an ongoing research project with the aim of modeling the corrosion rate (mm/year) on steel sheet pile structures along the Swedish coast line. The national and international literature on similar work has been reviewed. Earlier investigations on the corrosion rates along the Swedish east coast – with a salinity ranging from about 0.2% to approximately 0.8% – were performed in the 70´s and 80´s. The results from these investigations are still used today as guidelines for corrosion rate on steel structures in Swedish maritime environment even though the salinity on the west coast can be as high as 2.5%.

Data from ultrasonic measurements on steel sheet pile quays located along the Swedish coast was collected and studied. The measurements have been performed by diving entrepreneurs on behalf of the port authorities or consultants with the purpose of estimating the condition of the quays. The environmental conditions in the ports vary widely between the investigated sites. The salinity of the water (in the surrounding sea) ranges from about 0.65% to approximately 2.5%. Despite this, no correlation between salinity and corrosion rate could be found from the results of these measurements. Possibly do other factors – for example the traffic intensity in the harbors – have a larger influence on the corrosion rate than the salinity.

1 Introduction

The Swedish maritime transport sector – including the Swedish harbors – is experiencing a renaissance today. Since the volume of transported goods by sea increases along with larger freight vessels, this sets demands on the quays and ferry berths which are used by these transport ships. A large share of the existing quay structures in use today are steel sheet pile constructions. Many of these quays have reached an age of 60-70 years and often suffer from severe corrosion (Fig. 1). Due to the increasing volume of transported goods in the harbors, the loads on the quay decks also tend to increase and the actual loads on old quay decks sometimes exceed the design loads, which can lead to a collapse of these structures.

Figure 1: Sheet pile wall on the Swedish east coast suffering from severe corrosion (Joakim Brogstam, MarCon Teknik AB)

With knowledge about the sheet pile dimensions and year of installation, it is possible to estimate the corrosion rate expressed in mm/year after measuring remaining thickness in the sheet piles. This information is valuable for the structural engineer who shall verify the bearing capacity of an existing sheet pile structure. This data is also valuable when designing new sheet pile structures, which, in Sweden, often have a prescribed design life time of 120 years. Having knowledge about the actual corrosion rate at a certain harbor site gives both economic and environmental gains when optimizing this kind of structures.

This paper is part of an on-going research project with the aim of finding a model on how to determine the corrosion rate for steel sheet piles along the Swedish coast. The work has begun with an inventory of measurements performed in Swedish harbors together with literature studies. Since there is a significant variation in the conditions along the Swedish coast-line – this is especially for the large variation in salinity – it is expected that there also will be significant differences in corrosion rate along the coast. Parameters influencing the corrosion rate could for example be salinity, temperature, and the presence of a biofilm.

The most commonly used pile sections in harbor constructions in Sweden are Z- and U-profiles (Fig. 2). The sheet piles are delivered in steel grades with minimum yield strength between 240 and 460 MPa. Steel with copper addition for improved corrosion resistance can be delivered on request, but steel alloyed with copper, chrome or phosphorous has in practice not been found to be more corrosion resistant in soil and water than normal carbon steel [1].

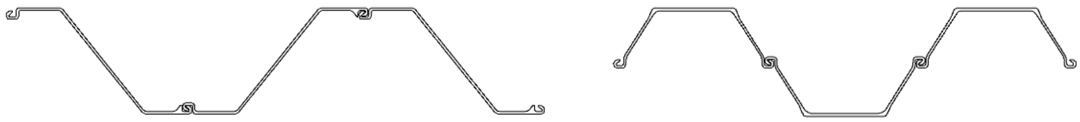

Figure 2: Z-profile and U-profile

When designing a new sheet pile quay there are several aspects to consider. The geotechnical conditions are for example of great importance for the final operation of the structure. Sometimes it is necessary to replace the natural soils behind the quay wall to better filling material. Other design criteria are the prescribed ground load on the quay deck behind the sheet pile and the prescribed service life of the quay.

A steel sheet pile structure can be designed in several ways. The most common quay structure in Sweden today is a back anchored steel sheet wall as shown in Fig. 3. The wall is back anchored either in bedrock or in anchor plates behind the wall itself. The material used in the tie rods is steel and the anchor plates are usually precast concrete slabs or steel sheet piles.

The most sensitive section in a sheet pile wall is about one third of the excavation depth from the sea bottom where the highest bending moment occurs. The largest shear force is located at the level of the attachment of the rods (Fig. 4). Because of this it is important to detect potential weaknesses in the flanges below the water surface *and* in the web at the location of the attachment of the tie rods. If the sheet pile wall supports the direct vertical load from for example a crane, the corrosion of the whole section is to be considered since this load case gives rise to additional compression tension over the whole sectional area.

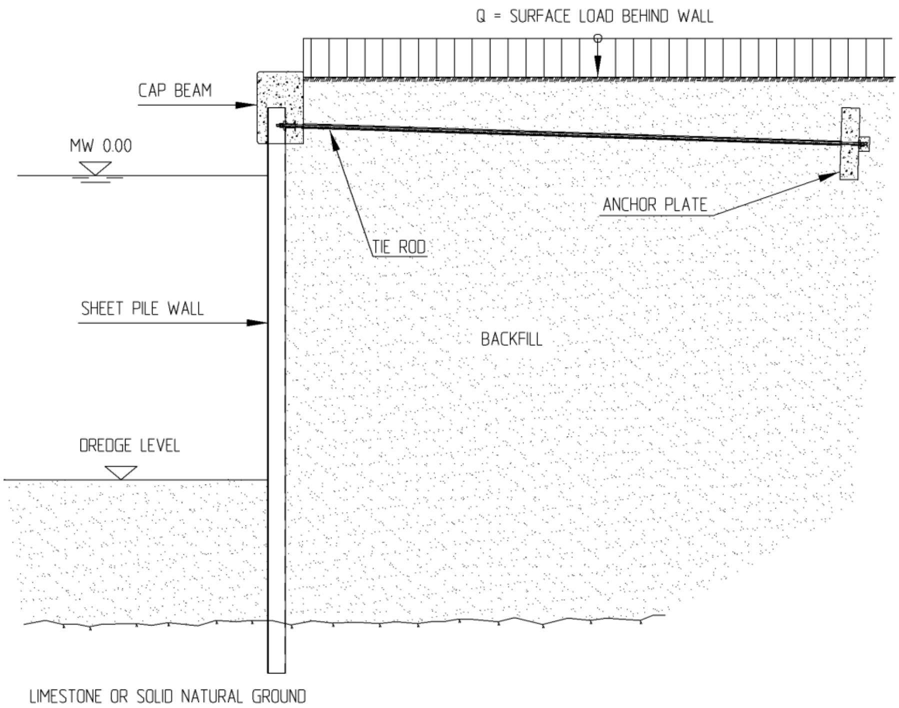

Figure 3: Standard back anchored steel sheet pile wall

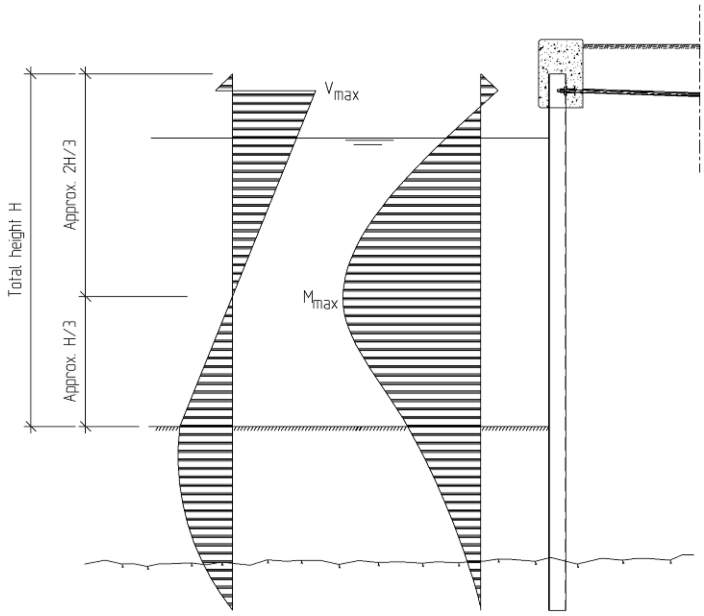

Figure 4: Bending moment (M) and shear force (V) diagrams for a standard back anchored sheet pile wall

When estimating the corrosion rate at a certain location, it is important to consider all the factors that influence corrosion processes. In Sweden we have rather large variations in temperature over the year and the salinity ranges from approx. 0.2% at the north east coast, to around 3.0% at the north west coast (Fig. 5a). In the Northern Baltic sea the ice loads can be rather heavy on the sheet pile structures as the number of ice days can be as high as 130 [2].

The corrosion rate below the water surface is also influenced by the traffic frequency in the harbors. The propellers oxygenate the water and in some cases erode the protective corrosion products from the steel [2, 3].

Another factor that influences the corrosion rate on steel sheet piles in regions where tide is present is accelerated low water corrosion (ALWC). This is an aggressive corrosion phenomenon induced by microorganisms at or just below the low-water level [4, 5]. However, ALWC has according to reference [5] not been found in the Baltic Sea and it seems to occur only in those coastal areas that are strongly influenced by tidal water. The low tidal water movement in the Baltic Sea can thus explain why ALWC is not found on the Swedish east coast. It could, however, exist on the west coast where there is a small tide.

When investigating existing steel sheet structures, one usually measures the uniform corrosion rate over a certain area of the structure. This is, however, a simplification of the corrosion process on this kind of structures, since there is also often pit corrosion, which is concentrated to small areas. Pit corrosion can give very misleading results when measuring the steel thickness with ultrasonic gauges. The most severe corrosion in Swedish sheet pile structures normally appears in the splash zone where the steel can be entirely gone when almost no corrosion can be detected a couple of meters below mean water level. This complicates the estimation of the status of the structure.

Corrosion of steel sheet piles along the Swedish east coast has been investigated earlier, see for example references [1, 2]. In reference [1], which is based on an extensive survey of corrosion data on steel piles and sheet piles in soil and water, guidelines are given for the corrosion rates in freshwater, brackish water and in sea water. These proposed design values in sea water are given in Table 1.

These recommendations are derived of results from thickness measurements performed along the Swedish east and south coast where the salinity ranges between 0.2% and 0.8% in natural sea water. No data on corrosion rates along the west coast had been collected, something which the authors of the report states as a question to sort out.

Table 1: Proposed design values on corrosion rates along the Swedish east and south coast [1]

Zone	Recommended design value for corrosion rate (µm/year)
Air zone above splash zone	≤ 100
Splash zone	≤ 300
Submerged zone	≤ 100
At bottom with non-eroding sediments	≤ 100
At bottom with eroding sediments	≤ 300
In sediments below bottom surface	≤ 50

2 Method

The most common method for determining the remaining thickness in steel sheet piles in Sweden today is measurements with an ultrasonic thickness gauge. This is a non-destructive method and there are a number of suppliers of such instruments on the market. Another method of determining the steel thickness is to cut out steel pieces of the quay wall and measure the thickness with a caliper gauge. However, this is a destructive method which demands expensive repairs after the sampling. The uncertainty of the soundness of such repairs is also a factor to consider when choosing sampling methods for this type of investigation.

The measurements presented in this paper have been performed with a Cygnus Underwater ultrasonic thickness gauge (Cygnus Instruments Ltd, Dorchester, England). The precision of the instrument is ±0.1 mm according to the manufacturer. The device uses a triple echo verification which means that no thickness value is displayed unless the times for three consecutive bounces of the ultrasonic signal are equal.

The measurements presented in this paper are from investigations performed by divers in Swedish harbors. The clients are either the port authorities themselves or consultants who are hired for the purpose of determining the status of a specific quay structure. The data has been collected from steel sheet quays starting south of the city of Stockholm on the east coast down to the south coast of Sweden and up along the southern half of the east coast (Fig. 5b).

a b

Figure 5: The salinity (‰) in sea water along the coast of Sweden (5 a) and locations of investigated harbors (5 b)

3 Results and discussion

In Fig. 6, corrosion rates from some of the investigated harbors are presented. An extensive amount of data has been collected and analyzed, but only the data from sheet pile quays with known year of installation are shown, as it is not possible to calculate the corrosion rate for the other structures. The observation points that have zero mm steel thickness left (holes) have been excluded in Fig. 6.

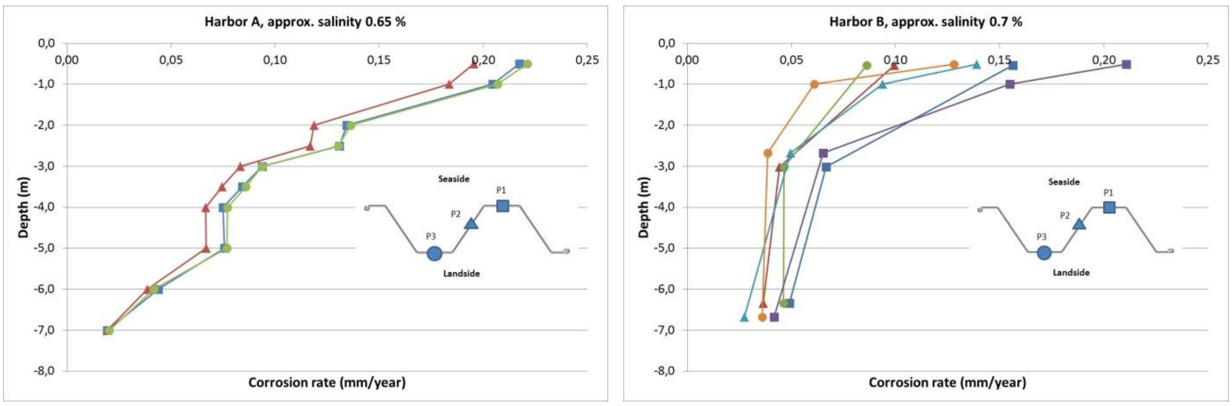

Figure 6: Corrosion rates along the Swedish coast

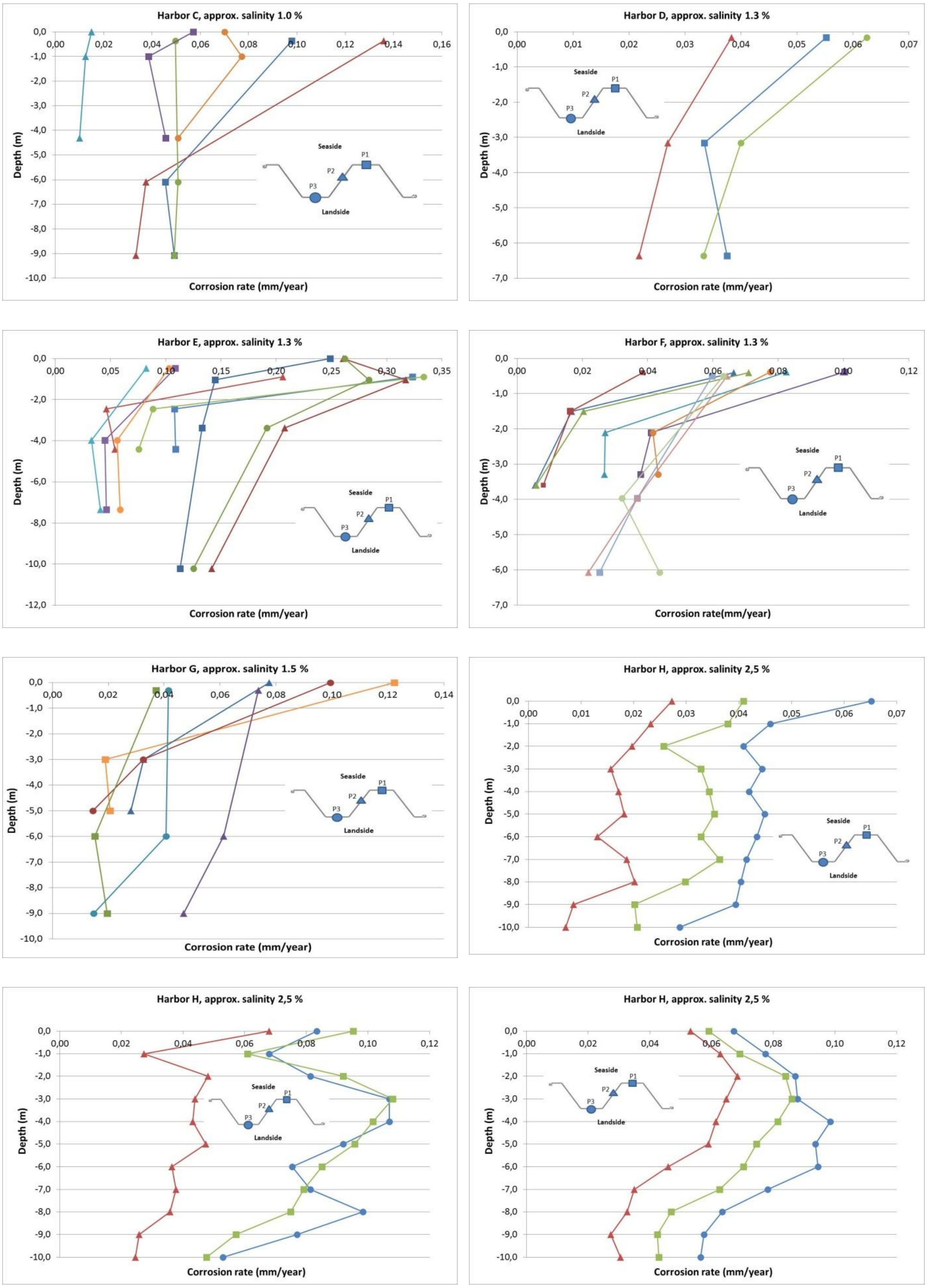

Figure 6 (cont.): Corrosion rates along the Swedish coast

As seen from the graphs (and as expected) the highest corrosion rate occurs in the mean water zone. However, the influence of salinity on the corrosion rate is not clear. When looking at the results from the east coast with salinity about 0.7%, the corrosion rate in the mean water zone varies between approximately 0.1 and 0.22 mm/year while the corrosion rate in the same position on the west coast with a salinity of between 0.8% and 1.5% varies between approximately 0.01 and 0.35 mm/year (Table 2). Note that some of the inspected quays on the west coast are equipped with cathodic protection.

Table 2: Measured corrosion rates along the Swedish coast. Quays with cathodic protection are marked “Anode”.

Location	**Approx. salinity (%)**	**Corrosion rate at MWL (mm/year)**	**Corrosion rate at -3m (mm/year)**
A	0.65	0.20-0.22	0.08-0.09
B	0.7	0.08-0.22	0.04-0.07
C	0.8	0.02-0.15	0.01-0.09
D	1.3	0.04-0.06 (Anode)	0.03-0.04 (Anode)
E	1.3	0.08-0.33 (Anode)	0.05-0.24 (Anode)
F	1.3	0.04-0.10	0.01-0.05
G	1.5	0.04-0.12 (Anode)	0.02-0.07 (Anode)
H	2.5	0.025-0.1 (Anode)	0.017-0.11 (Anode)

A problem with these kinds of measurements performed by diving entrepreneurs is that background data about the surrounding climate and environmental load often is missing. Also background data about the inspected structures, such as year of installation and steel sheet profile type is also sometimes missing. This makes it impossible to predict the remaining service life of the structure even if the thickness measurements on the steel are accurate and precise. Another problem is that harbors are often located at the outflows of rivers or other watercourses that dilute the sea water in the harbor area so that the salinity becomes lower than in the open sea outside the harbor. This can be positive as the corrosion rate generally increases with increasing salinity [6]. However, the flow from the river may increase the oxygen content of the water, which should favor an increased corrosion rate. The flowing water can also contain sediments that can give rise to increased corrosion by erosion by removing protective corrosion products on the steel. In other words, it is a complex problem to evaluate the corrosion rate in a marine environment.

There are several problems when evaluating these kinds of measurements. Wrong back-ground data, such as wrong input data for the original steel thickness is one problem when estimating remaining service life for the structure. The year of construction can be difficult to find, especially if the investigated structure is old, since the original drawings often are missing. In some cases already used sheet piles are installed in new constructions to reduce the construction costs. This makes it impossible to predict the true remaining service life of such a structure (if the steel thickness is not measured at the time of installation in the new structure). The geometric tolerances are also to be considered when evaluating the results from the measurements. Regarding the steel thickness in new sheet profiles the tolerance is about 5% of the prescribed thickness, which means about ±1 mm.

When performing measurements on quays with ultrasonic equipment, the investigated surface must be cleaned. Cleaning is often done with a wire brush or with a water jet. In some cases a pneumatic grinder is used, but then there is a large risk of unintentionally reducing the thickness of the goods, which in turn gives invalid results when performing the ultrasonic measurements.

One experience from a field investigation in early spring 2011 is that the size of the probe on the ultrasonic equipment is of importance for the results. Two probes with different diameters were tested at the same time in the same investigation points. The larger probe had a diameter of approx. 13 mm and the smaller one had a diameter of 6-7 mm. The investigation showed that the smaller probe could accidentally give thickness values in small pits while the larger one did not give any results at all in a pitted area because of the roughness on the steel surface.

Another aspect is the working environment for the divers who are performing the measurements. The water in our harbors is seldom clear and the visibility below the water surface is often limited. This along with several other distractions could give rise to wrong results. For example has measurements performed at our laboratory with the Cygnus Underwater ultrasonic gauge shown that there is a risk of getting wrong thickness results if the probe is held at an angle to the investigated surface.

4 Conclusions

The salinity at the locations of the investigated sheet pile quays range from about 0.65% to approximately 2.5%. The results from the ultrasonic measurements do not show any correlation between salinity and corrosion rate.

Tests in our laboratory and field tests shows that small probes could give misleading thickness values of the steel due to pit corrosion. The studies in the laboratory also showed that there is a risk of getting wrong results if the ultrasonic gauge is held at an angle to the investigated surface.

5 References

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