Keel report 2025

Tønsberg – 06.06.2024

NSA – KEEL REPORT 2025

To:	**Working Group:**	**Date:** 15.03.2025	**Version:** v1.1
NSA ISA	Harald Hilde, NSA Sigbjørn Berge, NSA Rune Johansen, NSA	08.08.2025 (v1.2)	v1.2: analyse of bolt (pg14), updated list of contributors

Background / Goals:

In Norway, there have been two incidents involving the lifting of a Soling using the centre lift. Fortunately, neither of these incidents resulted to human injuries. The incident with NOR 103 resulted in severe damage to the boat.

The Norwegian Soling Association, NSA decided to establish a Working Group (WG) to investigate the NOR 103 incident. The primary goals of this group are to understand the root cause for the incident, identify lessons learned, and share the information within the Soling community. The Soling fleet is aging, and it is likely that boats will require preventive maintenance to ensure that similar incidents do not occur in the future.

Disclaimer:
Information and lessons learned should be accessible to everyone within the Soling community for free
These are the WG's expressed opinions and recommendations, without those being professionally validated.

Contributors to the report:

NSA would like to thank experts for comments, online information, photos and all voluntary contributions to the report.

- Oddvar Moe, Technical Manager Tingstad AS.
- Georgios Nikoltsis, professional expert and editorial inputs.
- Bjørn Guldbrandsen, for description of the NOR 103 incident.
- Ove Sundsdal, NDT / Welder inspector
- WG:
  - Sigbjørn Berge, Mechanical Engineer.
  - Rune Johanesn, Deck officer.
  - Harald Hilde, Automation Engineer.

- Photos taken by Lars Ingeberg, Rune Johansen, Ole Morten Andresen and Harald Hilde.

- https://tingstad.no/
- https://coxeng.co.uk/metallurgy/fatigue/

Comments can be made on NSA's Facebook page: **Norsk Solingklubb - Forum & Bruktbørs**

Contact person for NSA and the report: harald.hilde@outlook.com

Summary:

The development of corrosion in the keel bolts for NOR 103 was identified as the root cause for the incident. The portion of the bolts that extended into the Glass Reinforced Plastic, GRP showed damage from corrosion and/or fatigue resulting in a degradation of the strength of all keel bolts. Fatigue is common in bolts, where the primary cause is under tightening. The choice of different material grades for bolts and washers/nuts as well the dissimilar nature of the various steel grades in an environment with constant salinity led to galvanic corrosion. When a higher-grade stainless-steel washer and nut are used with lower grade bolt in seawater, the bolt will corrode.

The top of the cast iron keel showed signs of crevice corrosion, indicating also possible water ingress over time. The portion of the bolts which was in contact with the cast iron part of the keel, seem not to be severely affected as they were protected by sealer.

Corrosion is a vast area of expertise, and there is a lot of literature to study. A small extract of the topic is included in the Technical paragraph.

The WG has not found any written guidance or descriptions on how to check or verify the condition of keel bolts.

The WG recommends periodically checking the keel/hull area for cracks and the keel bolts for corrosion and tension.

The WG recommends replacing bolts if they are corroded. Various tools and methods are available for changing bolts. WG recommends the use of the same material grades for bolts, washers, and nuts. WG proposes A4-80 or A4-70 as a suitable choice and the use of sealant between the stainless-steel bolt and the cast iron keel to mitigate galvanic corrosion. Use of sealer should extend also between the bolt and GRP to prevent sea water ingress.

If there are signs of corrosion, cracks and constant need for bolt retention, drop the centre lift and use slings positioned fore and aft of the keel to the lift the boat, as those might be signs of a connection with diminishing integrity.

NSA hopes that this report will lead to increased knowledge about necessary and adapted maintenance that will give Solingen a long life and fantastic sailing experiences

Observations:

The pictures taken of the keel of NOR 103 on the same day and just after the incident, provide a good basis for assessing the corrosion of the keel bolts. The two bolts, #1 (most rear) and #4, is used for the centre lift were heavily corroded in the area above the hull with the washer and nut. The remaining strength of these bolts were reduced to the grey area in the middle of the bolt, see NOR 103 Pic 4a, 4b, 8a and 8b below.

The presence of different steel grades in the keel, bolts, washer, and nut can explain the occurrence of corrosion. Corrosion can result from differences in corrosion potential alone or from a combination of galvanic effects and stress corrosion cracking or a combination of both. The material grade with the lowest corrosion potential becomes a sacrificial anode.

In the area at the top of the keel, hull, and bolt, the keel has the lowest corrosion potential and acts as the sacrificial anode. As seen on NOR 103 and in Pic 17, the threads of the bolt that are screwed into the keel have their original shape and diameter as if the bolts were new.

The keel is fastened on the GRP, with washer, and nut. The bolt has tension from holding the keel, has the lowest quality, and therefore acts as the sacrificial anode.

Bolt #8 seems to be a bolt with low corrosion. This bolt most likely broke when the boat was lifted for the second time while lying on the quay. The load of the keel was transferred to bolt #8 during lifting and the remaining glue around bolt #5, 6,7 and 9. All other bolts are corroded and broken area around the hull, washer, and nut.

The WG has not found any Function, Operation, and Maintenance documentation for checking the condition related to corrosion of keel bolts from vendors or from ISA. The use of "sacrificial anode" is commonly used for corrosion protection of vital functions in boats. To our knowledge, there is no protection in use in any Soling boats today.

Recommendations:

1. Corrosion Check:
   - Inspect all Soling keel bolts for corrosion often, especially if the GRP part of the hull inside the boat is dark-coloured.
   - Remove the nut and visually inspect the bolt, washer, and nut. Use a magnet to verify the material grade. If one of the three components is magnetic, corrosion is likely to occur.
   - An experienced person should evaluate the condition of the bolts and recommend actions. If the bolt is corroded and evaluated to be reused, reinstall the washer and nut, and tighten with a proper torque. A work procedure is suggested in paragraph **Tightening torque for keel bolts** below.

2. Bolts, reuse or substitution:
   - If bolts are in good condition and reused, record the torque used on the bolts and used this as a reference for future inspections.
   - If bolts need to be substituted also washer and nut should be changed. Quality A4-80 or A4-70 seems to be a good choice.
   - Always use suitable sealer to prevent water ingress from the hull and into the hole in the GRP, as well as separating the bolt from the cast iron keel.

3. Cracks Between Hull and Keel:
   - If cracks are observed between the hull and keel, check the tension in the keel bolts.
   - Seal cracks to prevent further expansion and crevice corrosion when water enters the keel.

4. Lifting:
   - The boat weigh is about 1050 kg as an example.
   - When using the centre lift, each of the two bolts must hold min. 525 kg.
   - If the lifting bolts have reduced strength, or to reduce risk, two hoops can be installed as can be seen on NOR 61, Pic1 below. This reduces the load on each of the 4 bolts to approximately 280 kg.
   - Using slings is highly recommended as the weight of the boat/hull “sits” on the keel and almost no load is forced on the bolts.
   - **Implement security measures when lifting.**

5. Water Drainage:
   - Always drain water from the keel after use. For winter storage and if there is a chance of water in the keel, tilt the boat backwards and the water is flowing away from the keel bolts.

Tightening torque for keel bolts:

The challenge we are facing is that we are dealing with not isotropic materials. This means that the GRP has different properties regarding tension and compression than the iron keel, bolt, washer and nut.

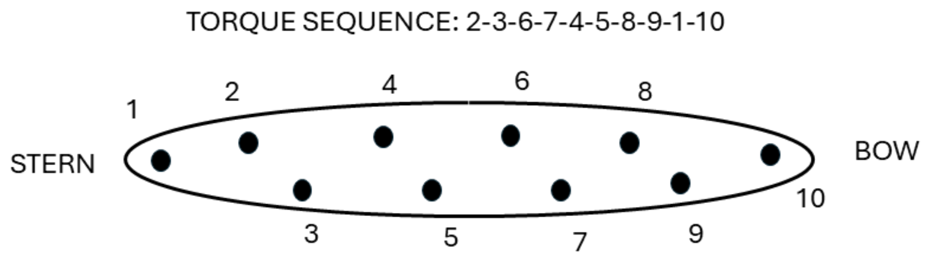
Torquing a connection where GRP is the material being compressed, can lead to a number of challenges, including the following:

- Squeezing the GRP at a point at which its effective thickness is being reduced
- Partial delamination
- Uneven bolt pretention amongst the 8 bolts
- Need for constant bolt re-tension
- Potentially stripping the threads in the iron keel

To obtain a correct tightening torque, the keel should be hanging free. Pre tighten the keel bolts with low force/torque number when the boat stands on the keel. Then lift the boat with slings, attached fore and aft of the keel and tighten the bolts.

Recommended work procedure:

- The work procedure is to manually tighten the bolt. Use standard wrench and tighten as tight as much as you can without the use of extenders or other special tools. Then use a tightening torque to read the torque value by starting with a low number and increase until you find the number obtained by the manual tightening. Repeat the same for the remaining bolts and note the torque figure for each of the bolts. Those notes can be used as a basis for comparison for future maintenance and bolt re-tightening.
- Suggested sequence for tighten the bolts:



The WG hope that there is experience that can give us useful feedback to answer this question:

What is the best work procedure and torque for tightening the keel bolts on a Soling?

Technical: 'Corrosion,' the metal chemistry working in the boat

Note from Tingstad AS: *You are welcome to use text from the catalogue and refer to the Edition I, as it was previously printed in larger editions in a period when the requirements for source references were not as strict. For a more thorough understanding of the problem described in the report, you should look for sources with relevant information about corrosion on the internet.*

General information copied from Tingstad AS catalogue: 'Technical Information' Edition I, Chapter 6, Corrosion.

Metals corrode as a result of the laws of nature. When producing metals from ore, energy is supplied, and the metal then reaches a higher energy state. Under certain conditions, the metal will transform from the more energy-rich to the more energy-poor state. This transformation is called corrosion and is caused by chemical or electrochemical attacks from the environment on the metal.

The conditions that cause corrosion are many, and there is therefore great variation in the types of corrosion that occur. Different types of corrosion include:

- General corrosion
- Selective corrosion
- Crevice corrosion
- Intercrystalline corrosion (grain boundary corrosion)
- Pitting corrosion
- Erosion corrosion
- Corrosion fatigue
- Stress corrosion
- Galvanic corrosion

General corrosion is corrosion of the entire surface of a metal under the influence of weather and wind. The corrosion of the entire surface is uniform and can be expressed in weight loss per unit area and unit of time (g/m^2h).

Crevice corrosion occurs when liquid penetrates a crevice and an uneven oxygen supply to the liquid occurs. Severe corrosion attacks can result.

Pitting corrosion is a localized type of corrosion that attacks a point on a surface. On stainless steel, pitting corrosion occurs in environments where the steel is exposed to chlorine solutions, even in very small concentrations. Chlorine ions dissolve the passive layer and the underlying base metal is attacked. Molybdenum and chromium counteract pitting corrosion positively.

Corrosion fatigue is a condition caused by a combination of dynamic stresses or vibration and corrosion. The condition leads to fracture damage and failure.

Stress corrosion cracking is a phenomenon that occurs when, for example, screws are pre-stressed in a corrosive environment. Almost all alloy systems are vulnerable to stress corrosion cracking in one environment or another. Only metals in their purest form are relatively immune.

Typically, screws are pre-stressed to 50% of the yield strength or higher, and the designer should therefore always be alert to problems with stress corrosion cracking.

Carbon steel screws will be sensitive to stress corrosion cracking depending on the hardness of the material. Stress corrosion can occur in carbon steel screws of all hardness levels, but if HRC39 is exceeded, screws must be used with caution. Below HRC 35, the sensitivity is minimal, and above HRC 40, the sensitivity is very high. Alloyed steel with a lot of chromium reduces sensitivity at high hardness levels. For example, UNBRACO uses alloys with chromium precisely for this reason (SPS.9 or AISI 4340) and controls the hardness by staying within a smaller tolerance range (40-43 HRC against 39-44 HRC ISO). In the austenitic steels, it is nickel that reduces sensitivity to stress corrosion the most. For the material to be insensitive, amounts of 35-40% nickel must be added; however, levels of at least 25% will provide sufficient protection in most cases. The triggering mechanism is an interaction between corrosion and tensile stresses; by actively protecting the screw against corrosion, the risk will be reduced. Ferritic stainless steels and Duplex are more or less insensitive to stress corrosion.

Galvanic corrosion occurs when two different metals come into contact with each other in the presence of an electrolyte. Like metals go well together; unlike ones do not.

Different metals have different voltage potentials, and when electrically connected in the electrolyte, the least noble metal will become the anode and the most noble the cathode. The anode material will sacrifice itself and partly protect the cathode material from corrosion. The speed, the area that is attacked and covered by corrosion depends on the following factors:

- The difference in voltage potential
- The conductivity of the electrolyte
- The area of the metals that are in contact with each other.

The cathode material has the highest potential (-) and the anode metal the lowest potential (+). The current goes from the cathode to the anode through the electrolyte and back to the cathode. The anode dissolves and the cathode remain almost unaffected.

This effect can be actively exploited in the fight against corrosion by choosing fasteners in a material that is actively protected by the environment - the screw must therefore have a higher energy potential than the environment.

Description of incidents, information and findings.

This chapter describes the NOR 103 incident on June 31, 2024, as collected by the Working Group. Additionally, it includes information from NOR 101 and experiences from refurbishing NOR 112 and 155. Findings regarding the condition of the keel bolts on NOR 61, a 1969 model Selco, are also noteworthy.

NOR 101.

Boat information: Abbott 1983, KC-691-83, ISAF 2026

Owner's description of the incident: *I and a friend purchased an Abbott Soling this summer for leisure sailing and local racing. The boat is fitted with a center lift device connected to two of the keel bolts. The boat was lifted out of the water on Saturday (02.10.2020) for winter layup. While starting the lift with the boat partially out of the water, one of the keel bolts snapped and we quickly "dropped" the boat back into the water and subsequently lifted her with regular slings.*

NOR 103.

Boat information: Abbott 1979, KC-615-79, ISAF 1943

The boat was normally stored on land and launched into the sea before sailing competitions. Over the years, the boat underwent several modifications. The condition before the incident was as follows:

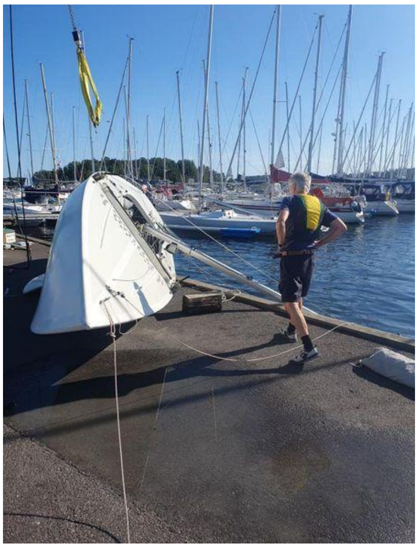
- There were long cracks between the keel and hull on both sides that had not been sealed. These cracks had been present for a long time and exposed the keel to salty water.
- Both lifting bolts were modified, as seen in picture 8a, with a shackle and fibre sling. The lifting wires was removed.
- In recent years, the boat was always lifted using the modified centre lift.
- There was about 100 litres of water in the keel before lifting. The plan was to drain the water once the boat was in the sea.

Description of the incident on June 6th, 2024 (as described by a crew member):

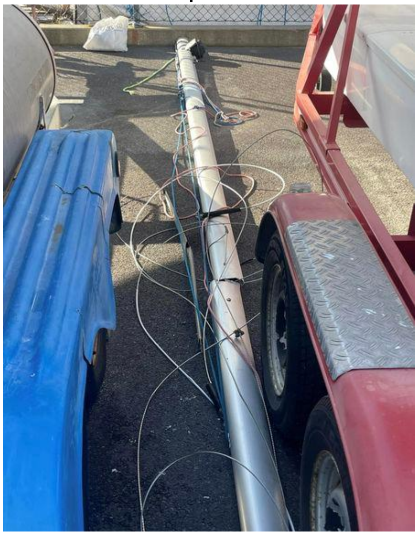
- The mast was moved forward. The aft stay had some slack to prevent interference with the crane's lifting chain.
- The trailer with the boat was positioned under the crane. The centre-lift slings were hooked to the crane, lifting the boat out of the trailer and manually swinging it towards the water.
- Just before the boat was over the water, bolt #4 snapped first, followed by bolt #1.
- The boat came down and remained on the concrete quay.
- The mast fell into the water and snapped at the spreaders.
- The fore and aft stays, as well as the upper and lower shrouds, were not broken in the incident (see pic 3).
- The mast was removed from the boat, and it was confirmed that the mast was broken in two at the point of the spreaders.
- The keel appeared to be well attached to the hull. The remaining strength of the bolts connecting the keel to the hull was not checked or evaluated.
- The boat was then attempted to be lifted with slings positioned at the hull, forward and aft of the keel.

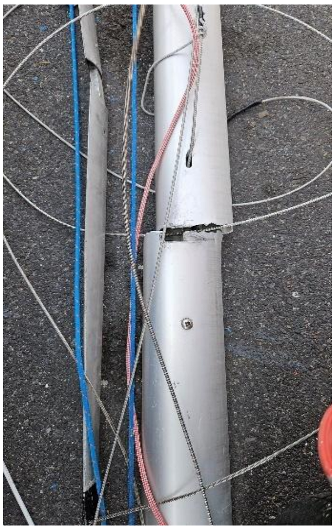
- Since the boat was lying on its port side, a twisting force from the keel to the hull was created.
- When the new lifting started, the keel separated from the hull and fell onto the quay (see pics 4a & 4b)

Picture 1&2: Tønsberg, Fjærholmen - June 6th 2024.



Pic 3 &3b: Mast broken at the spreaders.





Pic 4a: Keel and numbering of the bolts. Approximately 80% of the top of the keel is corroded and 20% with glue which also had some holding function of the keel.

Pic 4b: Keel case and cracks in the hull after the boat was stored in the trailer.
<u>Comment</u>: The cracks on the sides aft of the keel cannot be seen on pic 1. The cracks were made at the 2nd lifting of the boat. This also complies with how one of the crew remember the 2nd lift.

Pic 5a: Bolt #1, rear used for lifting. _Comment_: *Bolt is corroded around keel. Some glue on bolt to the hull. A grove on top which was the remaining strength of the bolt.*

Pic 5b Bolt #1: _Comment:_ *A fresh cut shows the remaining strength of the bolt.*

Pic 6: Bolt # 2, _Comment_: *Bolt strongly corroded for some time. Broken and no holding function.*

Pic 7: Bolt # 3. _Comment:_ *Bolt strongly corroded for some time. Broken and no holding function. Some 'glue' left around the bolt in 'hull hole'.*

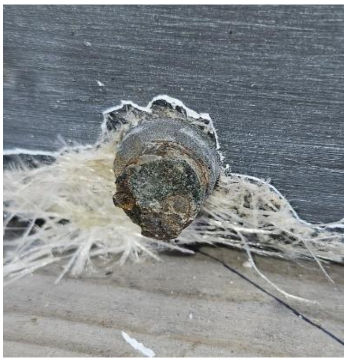
Pic 8a: Bolt #4 (used for lifting) _Comment:_ *Bolt corroded in the area of hull, washer and nut.* ***The incident started when this bolt snapped.***

Pic 8b: Bolt # 4. _Comment:_ *Modified shackle and fiber sling replacing the original wire.*

Pic 9: Bolt #5. *<u>Comment:</u> Bolt strongly corroded for some time in the area hull, washer and nut. No holding function. Glue around the bolt and on keel.*

Pic 10: Bolt #6. *<u>Comment:</u> Bolt strongly corroded for some time in the area hull, washer and nut. No holding function. Glue around the bolt and on keel.*

Pic 11: Bolt #7. *<u>Comment:</u> Bolt strongly corroded for some time in the area hull, washer and nut. No holding function. Glue around the bolt and on keel. Very little, if any holding function in the glue.*



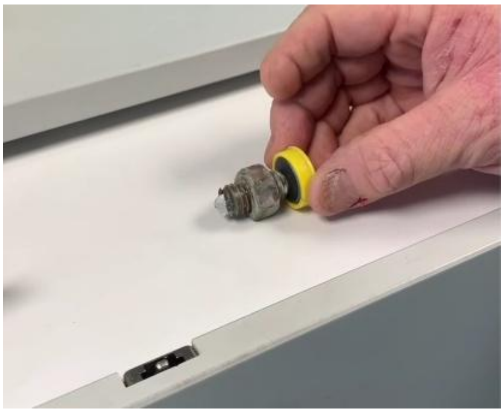
Pic 12: Bolt # 8. *<u>Comment:</u> Some corrosion of the outer part(ring) of the bolt. The 'clean' surface indicates the bolt snapped at second lifting of the boat.*

Pic 13: Bolt # 9 & 10 (at front). *<u>Comment:</u> Bolts have been strongly corroded for some time.*
Bolt #9 is corroded in the area hull, washer and nut. Maybe some holding function.
Bolt #10 is corroded in the area between keel and bolt. No holding function in bolt.

Pic 14; Magnetic test of Bolt #1 and Bolt #4 (with shackle)
Comment: *The shackle and bolts are magnetic*

Pic 15; _Comment:_ *The magneto test of bolt #1, bolt connects to the magneto*

Pic 16; _Comment:_ *The bolt #1 connects to the magneto and could be hauled over the table.*



Pic 17; All 10 bolts removed from keel.
Comment: *The bottom part of all bolts, which are in the keel have treads as they were 'new'.*
Bolt with ring is most likely the bolt #8.

Working Group (WG) Comments of the NOR 103 incident:

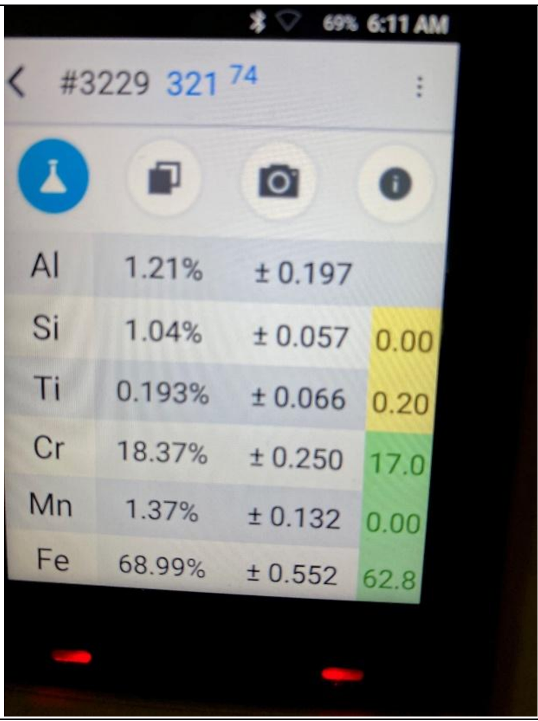
A. *The pictures above show that the boat had been exposed to corrosion of the keel bolt for many years.*
B. *Water accessed the top of the keel through cracks in the area between the keel and hull, leading to corrosion on top of the keel. The cast iron of the keel and the bolts are of different quality, and in combination with salty water, the keel corrodes.*
C. *On the inside, we see corrosion of bolts under the washer and nut. The corrosion is a result of difference in quality between the bolt, washer, and nut. The bolts are magnetic, whereas the washer and nut are not, which will expose the bolts to corrosion.*
D. *Experience and guidance on how to identify the weakening strength of keel bolts over time are limited within the Soling sailing community in Norway.*
E. *The boat had been lifted many times in 2024. The potential for an accident during these lifts was significant, and the WG thinks it was just a matter of time before the incident would have happened. That no one was hurt is regarded as pure luck.*
F. *The WG believes that the extra water (100l/100kg) in the boat this day could have been a trigger for the incident.*

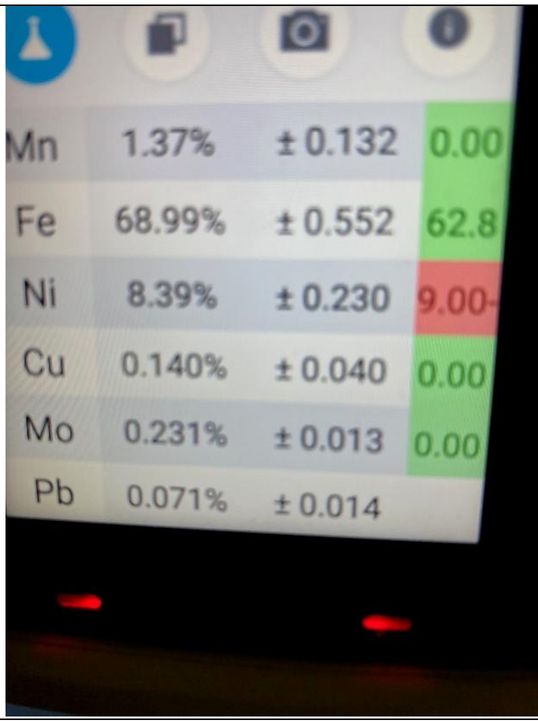
Analyse of bolt quality (update v1.2 - 05.08.2025)

One of the bolts was analysed. The quality is identified as ASI 304/304L.

This confirms that:
- Why the bolts are magnetic
- The keel is the sacrificing anode compared to the bolt. We see good treads, pic 17
- The bolts are sacrificing anode compared to nut and washer, which are better quality and not magnetic.

Screenshot from the analyse:





NOR 155.

Boat information: Abbott 1978, KC-547-78, ISAF 1873.

Description: The boat purchased by owner in May 2022. The boat was regarded as a wreck and on its way to the scrap yard. The condition of the keel can be seen on the picture below. A lot of refurbish work has been done on the keel and the boat in total. Focus here is the keel and bolts.
Long cracks between the keel and hull on both sides had been there for a long time and corrosion had developed over many years on the keel, ref picture 1.
5 keel bolts were damaged and had to be renewed, ref picture 2.

One observation, ref III. The hull areas around the bolts are not flat. The part facing towards the centreline is higher and causes higher pressure from the nut on the washer/hull than on the part facing away from the centre line of the boat.

Picture 1:

A long crack along the keel-hull and with a lot of rust on the keel. One the bolt in the hole is corroded or made like this?

Pic 2:

Hull had dark colour
Bolts 1-4 heavy corroded.

Pic 3

On the washers under the nuts there is a ring. This is probably from higher pressure from the nut at this part which was facing to Centreline of the boat.
The hull area under the spring is not flat, ref pic 2. The pressure made when tightening the nut is concentrated in this area.

Repair of keel and bolts:

The repair was done like this:

I: New square washers (40x40x3 mm).

II: One bolt was tried to be drilled out, but difficult to do. New bolt inserted in the same hole. New bolts 14mm were made from 1m tread-rod, 6-7cm each. Quality A4 -70 used.

<u>III:</u> For bolts that had to be renewed a new bolt was inserted on opposite site to the other. The foundation area under each bolt were made flatter by sanding away the Geal Coat and adding GRP spackle.

<u>IV:</u> Holes were drill true the keel and new treads made.

<u>V:</u> New Topcoat on the hull and bolts glued with Tread lock when inserted.

<u>VI:</u> 6 new bolts included one extra aft, 5 old bolts reused with new washers.

The boat was back in the water December 2024, racing.

NOR 112.

<u>Boat Information</u>: Abbott 1979, KC-603-79, ISAF1930

One bolt substituted: no picture available.

NOR 61.

Boat Information: Selco 1969, N-163-69.
Boat is planned to be repaired.

Observation. The bolts and nut are not magnetic. Some washers were made of aluminium. As can be seen on pic2 the washers are corroded.

Pic1 Keel inside, centre lift using a hoop on bolt 3 and 4.

Pic2, washers used is aluminium and corroded.

Pic3, bolt #2. Condition of treads seems to be ok, 55 years old. The condition of the bolt is not checked in detail.